Art Model Building of 3D Museum Based on Dynamic Octree Algorithm

Zhaofeng Wang

Agricultural University of Hebei, School of Art, Baoding 071001, Hebei, China

Yinfei Cui

Agricultural University of Hebei, School of Art, Baoding 071001, Hebei, China

Abstract

Aiming at the ineffectiveness and low operation rate when in art model building of 3D museum based on standard octree algorithm. This paper proposed an art model building of 3D museum based on a kind of dynamic octree algorithm characterized by model simplification and affine invariance. Firstly using point-by-point inserting method to insert the two peaks of constrained boundary into triangle network, searching the domain of influence of constrained boundary and using affine invariant to constrain the sample extracted from octree algorithm, and then making use of consistent coplanar four point set of Iterative selection to estimate european teansformation, selecting the estimative transformation with the best uniformity between the original and target set, finaly constructing the art model of 3D museum. The simulation experiment indicated that the proposed 3D simplified model based on constrained triangle network in this paper could well realize 3D point cloud simplification, and affine invariant dynamic octree algorithm had better effect as compared with standard octree algorithm in art model building of 3D museum.

Key words: DYNAMIC OCTREE, AFFINE INVARIANCE, 3D MUSEUM, ART MODEL, CONSTRAINED TRIANGLE NETWORK, 3D POINT CLOUD SIMPLIFICATION

1. Introduction

As a typical application of 3D virtual scene in the field of traditional culture protection and communication, 3D virtual museum becomes the main trend in the development of museum in recent years [1]. 3D virtual museum can break the space limitation of entitative museum, and get rid of the buildings, exhibition, visiting time which are necessary to traditional museum, greatly expand the wider space and the number of service object, increase the rate of cultural relics exhibition, improve display form and effect, make anyone visit museum by fast and convenient at any time and any place, maximumly expand museum function and be better to play cultural transmission and heritage protection functions of the museum [2]. Faced with such rich resources of cultural relics, how to quickly build 3d virtual museum becomes an important research issue.

Digital museum began in the 1990’s, countries around the world paied much attention to the protection of natural and cultural heritage, at present there are a large number of countries around the world are working on the construction of digital museum. In the 1990’s, the United states launched to construct construct multiple digital projects, such as American Memory plan, digital library pilot plan [3]. Canada also launched a plan of some famous figures, such as Quebec CHIN project plan [4]. The Aquarelle plan is supported by the European Union, this plan can support European museums share their resources on the Internet [5]. Japan's "Gobal Digital Museum (GDM) plan", supports different digital collection resources on the network, and also provides an interactive web browsing, editing, the main purpose of GDM program is to promote the museum education [6]. Digital museum not only contains a large amount of information database, but also use computer multimedia technology, through the map images, animation, display, implements image, video, and even voice, to provide users with easy-studying-easy-using and high affinity of user interface [7]. Digital museum also created a new mode of cooperation across disciplines and entities, and promote the integration of domestic and international resources and technology exchange [8]. In our country, the construction of digital museum has certain achievements, the representative museums are the Nanjing Museum, Dunhuang Museum, the Palace Museum, the Shanghai Museum and the museum of Chinese history, these museum informationizethe real museum informatization based on digital computer technology, and some digital museum also established the related topics in online museum [9]. In addition, the project such as "modern distance education online public resources construction of universitaire digital museum construction engineering" and "digital archaeological museum based on mass data processing grid " did a lot of research on digital museum [10]. In recent years, the rapid development of network technology and virtual reality technology created 3D virtual museum from scratch. Tomonori Usakai proposed a digital museum under the architecture of multi-user virtual environment , this architecture can provide multiple users with the interaction of the museum and communication based on the network [11]. Noboru Koshizuka et al. committe to the development of virtual museum in PDA terminal, such as virtual museum browse in PDA and other terminals through wireless sensor devices [12]. People are not satisfied simply browse the built virtual museum, but want to be able to participate in the creation of a virtual museum, it promoted to create the individual virtual museum system. Hong designed to create a framework of digital museum based on the users and used multimedia installation to create virtual museum [13].

This article started from the defect of octree algorithm, proposed a kind of model of 3D dimensional art based on simplified model and affine invariant dynamic octree algorithm, carried through experimental simulation and verified the validity of the improvement strategy.

2. Defect analysis of octree algorithm

Octree method was first introduced in the field of grid subdivision by Shephard and others, its basic idea is to use a cube to surround the problem domain, and then use octree to decompose recursively along the axial until meeting the required mesh density.

Octree structure is as shown in figure 1, which is the space area down to eight sub area with the same size, the more times the decomposition, the less the subdomain, until the single attribute in the same area.

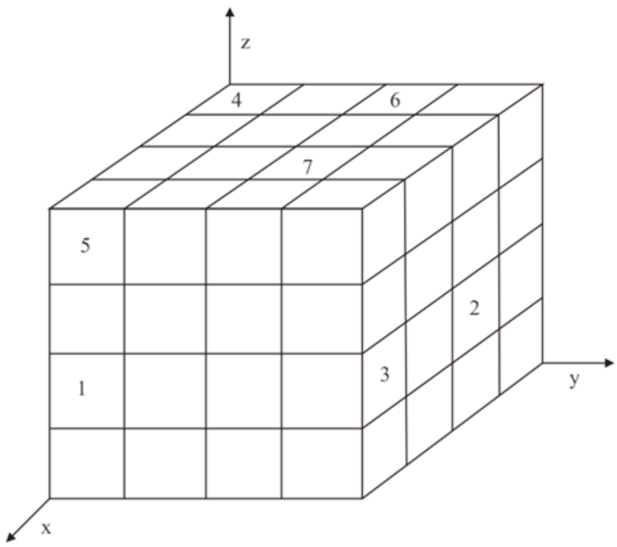

Figure 1. Octree segmentation model

Split test rule of octree space: marked as "black" if the corresponding regions is fully occupied by a target area; marked as "white" if not. Further split test for "black", repeated when using it for grid generation, until the length of sub-cube side is less than or equal to the given accuracy of segmentation. A cube, based on the above principles, is splitted to eight cube. Supposed (v_x, v_y, v_z) as the central coordinate of a cube, side length L, so the central point of eight sub-cube can be given by the equation (1):

$$\begin{cases} A_0 = v_x - L/4, v_y + L/4, v_z + L/4 \\ A_1 = v_x - L/4, v_y + L/4, v_z - L/4 \\ A_2 = v_x + L/4, v_y + L/4, v_z - L/4 \\ A_3 = v_x + L/4, v_y + L/4, v_z + L/4 \\ A_4 = v_x - L/4, v_y - L/4, v_z + L/4 \\ A_5 = v_x - L/4, v_y - L/4, v_z - L/4 \\ A_6 = v_x + L/4, v_y - L/4, v_z - L/4 \\ A_7 = v_x + L/4, v_y - L/4, v_z + L/4 \end{cases} \quad (1)$$

Each cube is divided into eight equal parts, so the model space is divided into a total $2^n \times 2^n \times 2^n$ sub-cubes. Making use of the characteristic of octonary number system from 0 to 7, any node location in octree space can be uniquely determined by one octonary number system:

$$Q = q_{n-1}8^{n-1} + q_{n-2}8^{n-2} + ... + q_k 8^k + ... + q_0 8^0 \quad (2)$$

q_i in equation (2) is octal code, $q_i \in [0,7]$, $i \in [1, n-1]$. q_i denotes the serial number of node between its full brothers; q_{i+1} denotes the serial number of node q_i parent node between the brothers. In this way, from q_0 to q_{n-1}, it is integratedly denoted that the path from every leaf node to the root in octree.

Each leaf node coding can be figured out according to the binary number of coordinate value (x, y, z) in the lower left corner of octree space, that is:

$$\begin{cases} x = a_{n-1}2^{n-1} + a_{n-2}2^{n-2} + ... + a_k 2^k + ... + a_0 2^0 \\ y = b_{n-1}2^{n-1} + b_{n-2}2^{n-2} + ... + b_k 2^k + ... + b_0 2^0 \\ z = c_{n-1}2^{n-1} + c_{n-2}2^{n-2} + ... + c_k 2^k + ... + c_0 2^0 \end{cases} \quad (3)$$

It can be obtained based on the relationship between each cube unit number in octree space:

$$q_k = a_k 2^2 + b_k 2^1 + c_k 2^0 \quad (4)$$

Similarly, if knowing one cube unit number in the octree, the coordinate value can be figured out:

$$\begin{cases} x = \sum_{i=1}^{n-1} |q_i|_2 \times 2^i \\ y = \sum_{i=1}^{n-1} |q_i / 2|_2 \times 2^i \\ z = \sum_{i=1}^{n-1} |q_i / 4|_2 \times 2^i \end{cases} \quad (5)$$

$|q_i|_2$ in equation denotes calculating residue after q_i after divided by 2, $|q_i / 4|_2$ denotes round number, n is segmentation layer or depth of octree space.

Similarly, if knowing one cube unit number, the coordinate value can be figured out by equation (4) and (5). According to the characteristics of the bounding box space, if space coordinate serial number of node bounding where node V placed is (x, y, z), the 26 minimum space relative number coordinates surrounding V can be denoted by the following equation:

$$\begin{cases} x' = x \pm 1 \\ y' = y \pm 1 \\ z' = z \pm 1 \end{cases} \quad (6)$$

In equation (6), $x', y', z' \in [1, L / L_{\min}]$ and x', y', z' cannot be equal with (x, y, z) meanwhile.

Octree method has the advantage of simple data structure, stronger geometric adaptability, controlled grid size, and higher efficiency of algorithm. When operations on intersection, integration and subtract for spatial entity, only need to traverse to set operation both form corresponding octree without complex intersection operation. The main problem that octree method facing is difficult to deal with grid generation near the border. In order to realize better approximation problem domain boundaries, it usually need to use excessive tetrahedron element on the boundary, but even so it is still hard to ensure the consistency of the original region boundary and the final mesh boundary.

3. Art modeling based on dynamic octree algorithm

3.1. 3D model simplification based on constraints triangle network

Triangle network is a geometric dual graph of 3D model, which is the triangulation connected by points in polygons adjacent area of 3D model

Supposed gather P as finite point set in two-dimensional real number domain, side e is close segment formed by concentrated points served as endpoint, E is the set of e.

Triangle network $T = (P, E)$ is a planar graph G of point set P, meeting the conditions: (1) no intersecting side; (2) except endpoint, any point in point set is not included in the side of planar graph; (3) all planes in planar graph are triangular, and all set of triangular planes are the convex hull of point set P.

If one side e (suppose the endpoint as a, b) in point set E meets the following conditions, e is named triangulation network side: there is a circle passing through point a and b, and in which there is not any point of point set V, this character is called empty circle.

If all sides of triangulation T in point set P are triangulation network side, then this subdivision is called triangulation network subdivision.

Point set composed of four points, one kind is as shown in figure 2. In this case, bd is not triangulation network side because the circle passing through b, d either contains point a or pint c. Intuitively, if point c or a on or outside circumcircle of the triangle abd or bcd, bd is triangulation network side. Actually, another definition of triangulation network subdivision is that when all the circumcircle forming triangulation network do not contain any point of point set, this triangulation is named triangulation network subdivision.

The basic idea for modeling based on triangulation network: for given point set $S \in R^2$, firstly construct a arbitrary triangulation and a series of side switch processing is done for formative triangulation network until all are triangulation network sides, in this way 3D modeling based on triangulation network subdivision is created.

Firstly use point-by-point interpolation method to insert the two peak point of constrained sides to triangulation network, and then search influence domain of constrained sides. With improved algorithm, all the constrained sides only exist the situation shown in figure 2, it means that the peak points of all constrained sides and discrete points are coincident. In this way when searching for triangle which peak point of constrained side located, it only needs cooperation between peak point of constrained side and triangular peak of triangulation network, and seek one or multiple triangles which include this point, use the relationship between constrained side and triangle to judge if there are multiple triangles.

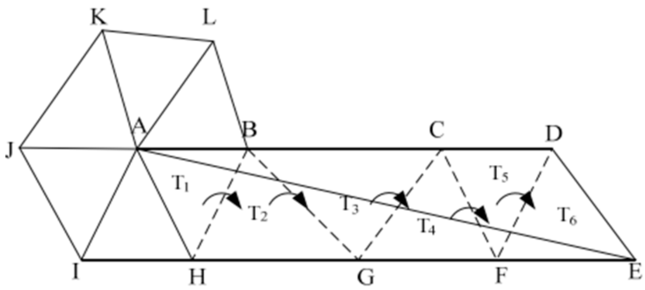

Figure 2. Domain affect search method

In figure 2, for constrained side AE, search for its influence domain. Firstly seek out the starting pint A of AE and terminal point E belong to ΔT_1 and ΔT_6, side AE intersects with side BH of ΔABH, then ΔT_1 as regards to ΔT_2 which is near side BH belongs to influence domain, until searching to ΔT_6, triangular union set meeting all the conditions $Q = \bigcup_{i=1}^{5} \Delta T_i$ is consider to be influence domain of side AE. When searching for the triangle to which A belongs, because 6 triangles contains point A, we need to find out ΔT_1 accorded with requirement, due to intersection between AE and side of polygon $BHIJKL$ consists of six triangle, hence seek out ΔT_1, same method for point E. When finishing search of influence domain, all the influence domain of constrained side can be well reconstructed using diagonal exchange method.

Summing up the above, 3D model building simplification steps based on the triangulation algorithm are as follows:

(1) Using dot interlace method to change all lines into discrete points;

(2) By the method of triangulation net growth, triangular network subdivision of discrete points is carried out to get triangle plane array;

(3) All triangular facet in traverse P, judge whether or not the side of the triangular facet is intersected with polygon boundary, if yes, adjust the two triangles which shares this side, transform quadrilateral diagonal the two sides formed, generate two new triangle surface instead of the original triangle surface; if no boundary intersection of line segments after complete traverse, entering the step (4)

(4) Traverse triangular facet, judge the relationship between the midpoint of an arbitrary center line of each plane and polygon outline. If the point outside the polygon, delete this triangular face in P.

(5) Calculate normal vector of all triangular facet. If contrary to plane normal vector, the first and the third side of this triangle swaps, use plane normal vector instead of triangle surface normal vector;

(6) Calculate all vertex normal vector, satisfy the requirement of visualization. End of the algorithm.

3.2. 3D art model building based on dynamic octree

Using affine invariant constraints octree algorithm to extract samples can effectively reduce the amount of sample, which can accelerate the rate of octree algorithm.

Supposed that the overlaps between original data set S and target data set T occupy ω of all data set. For the sake of easy, give out the estimation of overlap ratio ω directly. Calculate the length $l_{\max}$ between two furthest apart and data concentrated points under Euclidean distance, thus getting constraints length of distance between the point of four coplanar:

$$d_\omega = l_{\max} \cdot \omega \tag{7}$$

Randomly select a point S_1 in data set S and S_2, make them:

$$d_\omega - \sigma \le \|S_2 - S_1\|_2 \le d_\omega + \sigma \tag{8}$$

In above σ is a threshold with certain error and search for S_3, make them:

$$d_\omega - \sigma \le \|S_3 - S_2\|_2 \le d_\omega + \sigma \tag{9}$$

Meanwhile meet:

$$\min(\|\overline{S_2S_3}, \overline{S_2S_1}\|_2) \tag{10}$$

It means to make the distance length meet the constraint conditions at the same time, $\overline{S_2S_3}$ and $\overline{S_2S_1}$ should be vertical as far as possible.

Through previous three points $\{S_1, S_2, S_3\}$, we calculate the vector:

$$\overline{S_2S_3} + \overline{S_2S_1} = (S_1 - S_2) + (S_3 - S_2) \tag{11}$$

Which can be obtained S':

$$S' = S_2 + \overline{S_2S_3} + \overline{S_2S_1} \tag{12}$$

Searching for point S_4 closer from S' in original data set S and it should meet:

$$\min\left(\left\|\overline{S_2S_4}\cdot(\overline{S_2S_3}\times\overline{S_2S_1})\right\|_2\right) \tag{13}$$

The point S found under this condition should as far as possible be in the same plane with $\{S_1, S_2, S_3\}$.

Using above methods can select colane points $\{S_1, S_2, S_3, S_4\}$, and formative affine invariant among them is:

$$r_1 = \frac{\left\|\overline{eS_3}\right\|_2}{\left\|\overline{S_1S_3}\right\|_2} \tag{14}$$

$$r_2 = \frac{\left\|\overline{eS_4}\right\|_2}{\left\|\overline{S_2S_4}\right\|_2} \tag{15}$$

To do so is to constrain the quadrilateral shape to be square as far as possible and avoid uneven length in selection of quadrilateral , which can enlarge error and affect the match result. As much as possible while constrain the square shape of quadrangle, but the actual cases can't completely appears as a square, e cannot be the middle point, invariant r_1 and r_2 cannot be completely equal, but it won't affect the searching of consistent coplanar four point set.

Moreover, this method only needs two repeat randomly to selected points, to find the appropriate points S_2 and S_3 which meet the conditions, so the complexity of point selection is $O(n^2)$.

From previous analysis, it can make use of iterative selection for consistent colane four point set, estimate Euclidean transform H_c, and select between original data set S and target data set T under estimated transformation H_c, the best degree of consistency estimate transformation.

under estimated transformation H_c, the degree of consistency between original data set S and target data set T, use a certain error threshold δ to measure the number of consistent point.

Besides, constraint corresponding points in the direction of the surface, make them within a certain range of deviation. Suppose that $S_i \in S$ in original data set and $T_i \in T$ in target, it can be used the following equation to constrain:

$$\left\|T_i - H_c \cdot S_i\right\|_2 \le \delta \tag{16}$$

$$\frac{n_{T_i}\cdot n_{H_c\cdot S_i}}{\left\|n_{T_i}\right\|_2\left\|n_{H_c\cdot S_i}\right\|_2} \ge \cos\theta_\delta \tag{17}$$

In which n denotes the normal vector of point and θ_δ angle error threshold.

4. Algorithm performance simulation

In order to verify the performance of the improved algorithm proposed in this paper, with a 3D art model as an example, using a standard algorithm and improved algorithm proposed in this paper to conduct 3D model simplification, the comparing result is as shown in the figure below.

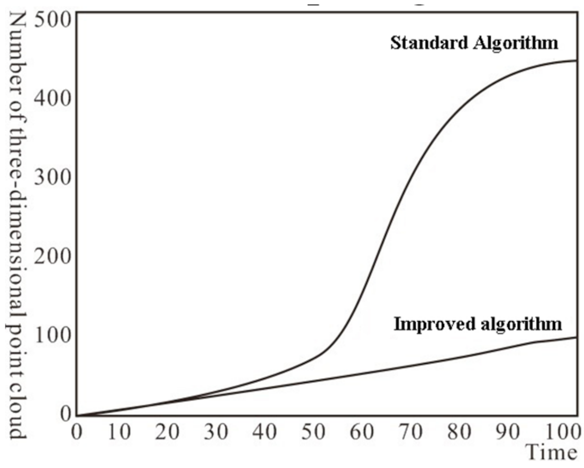

Figure 3. Number of 3D point cloud comparative results art model

Then, the dynamic octree algorithm is used to construct the 3D art model, and compare with the standard algorithm, the effect is as shown in the figure below.

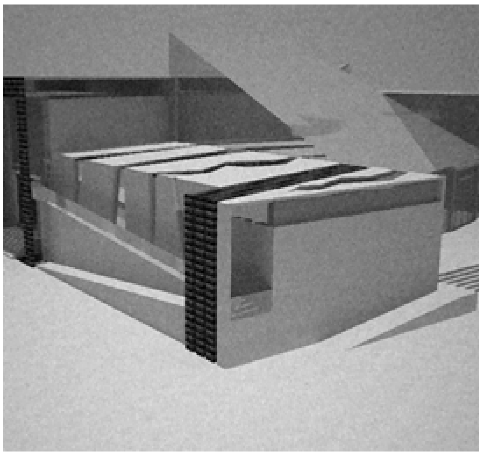

Figure 4. Art model standard octree construction

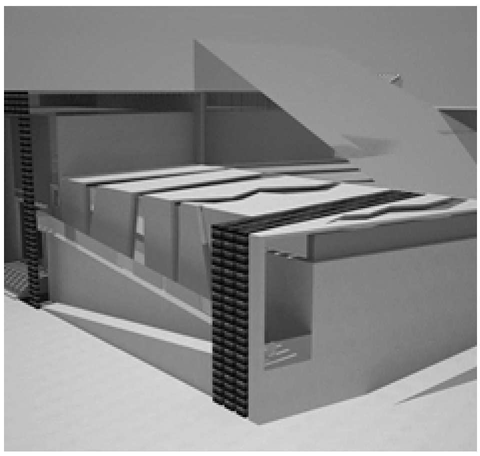

Figure 5. Improved art model octree construction

It can be seen from the above results, the proposed simplified model based on constrained triangulation of 3D can be a very good simplification of 3D point cloud, and the effect of affine invariant dynamic octree algorithm in the construction of 3D art model is better.

5. Conclusions

3D digital technology in the museum of archaeology and the application of is becoming more and more widely in recent years, 3D digital technology in the museum of archaeology and the application of is becoming more and more widely in recent years, from the establishment of the cultural relics of the 3D database to the establishment of the digital museum exhibition hall, it is widely used in the 3D digital technology. This article, started from the defect of octree algorithm, proposed a 3D model art based on a model simplification and affine invariant dynamic octree algorithm, the experimental simulation results showed that the proposed algorithm had a good effect compared with the standard algorithm in the construction of 3D art model.

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