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Research on Triangular Mesh Simplification Algorithm of Virtual Object Model

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Abstract: To improve the model quality of mesh simplification, reduce the model deformation and the lost of the detail characteristics with multiple folding, the paper represents a triangular mesh simplification algorithm based on edge-surface folding. The algorithm introduces curvature characteristics of model vertexes into the weight calculation of effective points, and introduces weight of triangular facets at the same time. The facets with the smallest weight adjacent the candidate edge is shrunk. The experiment results show that the algorithm has provided a higher quality of model simplification and effectively kept the graphic features.

Introduction

With the development of the requirement of computer model and render technology, the scale of computer simulation scene is getting larger and larger. In order to store, transport, display, reconstruct these models, it is necessary to simplify virtual these models firstly[1，2]. Simplification of geometric model refers to reduce the number of facets, edge and vertices of the model under the premise of keeping the original geometry shape of the model. For triangular mesh model has the advantage of express simplifying and is convenient to process uniformly[3], most of the grid model is expressed by triangle facet, and even if the original model is not triangles facets, arbitrary polygon can also be cutting into the triangular facets easily, so this paper aims mainly at the research of triangular mesh model.

The essence of simplifying mesh is to minimize triangular facets and the number of vertices of the original model and to keep original model characteristics as much as possible, with two simplifying principle: least vertices of the simplified model with given error; minimum error with given the number of vertices of the simplified model.

There are regular mesh simplification algorithms such as deletion method, vertices clustering method, segmentation method and remeshing method[4], etc. Deletion method is to delete one or more elements from the original triangle mesh model and triangle facets with the elements too. The method, most frequently-used method in mesh simplification, includes deleting vertex, folding edge and triangular facets.

When triangular meshes are deleted according to the criterion of common distance scale, many details in models with side information, such as trees, flowers, plants, mini-spare parts etc. is simplified, which influences model appearance. In order to keep these details characteristics better in simplification process, the paper is based on combination edge with facet folding , combines quadric error metrics mesh simplification algorithm[5,6] of the discrete curvature with shrinking facets algorithm based on the roughness grade to effectively reduce the loss and deformation of detail characteristics in multiple folding process.

Improved meshes simplification algorithm and smoothing based on the combination edges with facets folding

Curvature of curve indicates rotation speed of the curve's direction vector. Depicting the grid changing by approximate curvature for discrete grid can reflect the feature of grid surface[7]. On the flat area of grid, curvature value is smaller, however, it is greater on the edge and angle. Therefore, the surface feature of meshes can be digitized and incorporating the feature into the weight value of the vertices is very important.

Literature [8] proposed a simplified method based on Quadric Error Metric（QEM).The error measure is based on quadratic sum of distance from vertex to surface. The algorithm can calculate quickly. Although the algorithm can guarantee edge folding mainly in direction of smaller curvature changing, detail features of model surface may be also in this direction. Multiple folding in the direction may lead to deformation or loss of detail characteristics. Especially in the situation of fewer polygons, the model becomes rough, details loses more. the paper is based on combination edge with facet folding , combines quadric error metrics mesh simplification algorithm of the discrete curvature with shrinking facets algorithm based on the roughness grade to effectively reduce the loss and deformation of detail characteristics in multiple folding process.

Weight Calculation of Effective Folding Edge Based on the Point- Line Feature. In triangle mesh model, there are many feature points and lines, which largely influence the appearance of the geometric model. Merging without any analysis, only slight change of characteristic line may cause geometric figure seriously out of shape.

Before merging a pair of vertexes, the paper determines firstly whether the pre-merging vertexes is the feature points or feature lines to reduce the loss of model detail. Judgment criterion is as follows.

(1) If absolute value of the maximum vertex curvature in model is greater than its adjacent vertex curvature's, and the difference between them is larger than the threshold T, the vertex refers as feature point of the model. Feature points locate at edge angles in the model. When calculating weight value of vertex pair including feature point, the feature value of the feature point is k times (k > = 2) itself weight value instead to reduce the probability that the feature point is merged and remain the feature of edges and corners in the model to a great extent.

(2) If dihedral Angle composed by two shared triangular facets of one edge is less than the threshold value Φ , then the edge is the feature line of the model. Feature lines are on the model edges. When calculating weight value of feature lines, the weight affected by curvature is k times (k > = 2) itself weight value instead. The dihedral angle of model is computed as follow by cosine of angle between normal vectors of triangles facets,

$$\cos\theta_{V_{ij}} = -\frac{N_{f_i} N_{f_j}}{\left|N_{f_i}\right|\left|N_{f_j}\right|} \tag{1}$$

Where N_{f_i} , N_{f_j} are normal vector of two triangular facets, $\theta_{V_{ij}}$ is dihedral Angle.

Judge each edge when calculating vertex curvature of the model; judge whether the edge is characteristic line by calculating dihedral angle; judge whether vertex is feature point by comparing each vertex curvature and its neighbor vertex curvature and separate them from common vertex when simplified graphics through the piecewise function; try not to merge feature points and feature lines in the simplification process, and try to merge ordinary vertexes.

In order to introduce the influence of the curvature to the weight value, the paper uses error of vertex pair as a part of the weight value. The curvature and error of vertex pair together constitute the core part of the weight value. The error of vertex pair can be calculated by following formula,

$$\Delta(v) = v^T (Q_1 + Q_2) v \tag{2}$$

Where the Q_1, Q_2 are second-order error matrixes of vertex V1, V2 respectively. V is new vertex by merging V_1 , V_2. Weights calculation function of vertex pair is as follow,

$$F_{v_{ij}} = f(K_{v_{ij}}, \Delta(v)) \tag{3}$$

where $K_{v_{ij}}$ is the curvature influence factor, $\triangle(V)$ is error influence factor of vertex pair. This paper constructs weight function with the multiplication of two impact factors as follow

$$F_{v_{ij}} = K_{v_{ij}} \Delta(v) \tag{4}$$

Sorting triangle facets with weight. Triangle facets of model is sorted as follow

$$W(t) = BF_n(A(t)) * (wb * G(t) + (1 - wb) * V(t)) \tag{5}$$

Here， $BF_n(x) = x^n$ is the nonlinear control function of area, $A(t)$ is the area of the triangle T, $G(t)$ is the sum of adjacent triangles weight of three vertexes of T. $V(t)$ is new degree after triangle contraction, wb is parameter of control weight value for different sort factor.

$$G(t) = (G_1 * \mathrm{var}_1 + G_2 * \mathrm{var}_2 + G_3 * \mathrm{var}_3) / (\mathrm{var}_1 + \mathrm{var}_2 + \mathrm{var}_3) \tag{6}$$

Here, dihedral mean G_1 and variance var_1 is for Vertex P_1, dihedral mean G_2 and variance var_2 for Vertex P_2, dihedral mean G_3 and variance var_3 for Vertex P_3 respectively.

The grid contraction based on the weight value. Weight composition of vertex pair changes the priority of vertex merging. The edge with minimum weight value in mesh is firstly simplified, the smaller weight one of two adjacent facets of the edge is shrunk, algorithms' steps is as follows.

(1) According to the parameters of pair of vertexes, choose effective pair of vertex;
(2) According to the characteristic value and effective weight value of vertex pair based on quadric error matrix, put weight value into a binary heap, sort vertex pair by weight, put vertex pair with least weight value on the top of the heap;
(3) Computing the weight value of each triangle facet, put weight value into another binary heap, sort by weight value, put facet with least weight value on the top of the heap;
(4) Remove vertex pair with least weight e, search two adjacent triangular facets in another sort heap;
(5) Shrink triangular facet with smaller weight value;
(6) Recount the weight of vertex pair with new generated vertex and triangular facet, and update their e position in the pile;

Repeat steps (4)～(6) until reaching the requirement of model simplification.

Smooth processing. Generally speaking, the surface of mesh after facet reduction is not smooth, unevenness will appear, and hence the further smooth processing is needed. The smooth processing readjust space coordinates of the surface vertexes to get better appearance. Here a simple and effective Laplace smoothing algorithm is employed.

Laplace smooth algorithm is mainly adjust space position of drawing object, and it can not only make new triangle facet have better forms, but can effectively adjust the space distribution of surface vertexes. The main steps of the algorithm are as follows.

(1)Definite iterative processing number *N* of Laplace smoothing algorithm;

(2)Processing all surface points, for space point v_i, determine all the space points directly connected with v_i by the topology analysis;

(3)Store all the space points directly connected with v_i int an array A_i without repeat;

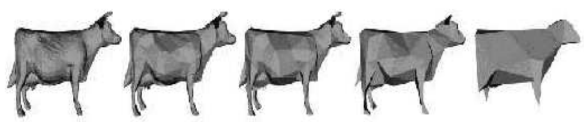
(4)Iterative processing point by point, calculate average space position of all the space points in array A_i, and assign the "average" position to v_i。

(5) Judging whether iterative times meet the requirement, if yes, then stop iteration and draw the surface object, or turn (2) to continue iterative processing.

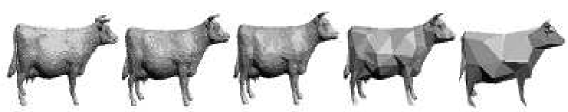
Laplace surface smooth processing can effectively eliminate the data distortion caused by the facet reduction, and draw the surface more actually and naturally. However, too much iterative adjustment increases the complexity of algorithm calculation with little impact on drawing impression. Therefore, in order to acquire better smoothing effect with less computational complexity, the iteration number of Laplace surface smooth processing should be better in 25 ~ 40 times.

Experimental results and analysis

In the experiments, QEM algorithm and proposed algorithm are compared. 5804 facets of cattle mesh model is simplified on PC with the configuration of Winxp sp2, AMD2500 + 1.4 G CPU, 2 G RAM:, ATI X550XT graphic card. The results are shown in Fig.1. Fig.1 (a) is simplified results by QEM and Fig.4 (b) is the results by proposed algorithm. The performance of the two algorithms is shown in table 1.



(a) Simplified results of QEM



(b) Simplified results of proposed algorithm

Fig.1. Simplified cattle mesh model by two different algorithms

Table 1. Performance comparison between QEM algorithm and proposed algorithm

paces	*Simplified* (%)	*Running Time(s)* *QEM*	proposde algorithm	*Error* *QEM*	proposed algorithm
2900	50%	3.760	3.543	1.8304e-6	1.8265e-6
1160	80%	5.820	5.611	2.203e-5	1.992e-5
580	90%	5.984	5.735	5.341e-5	5.027e-5
290	95%	6.691	6.561	2.560e-4	2.251e-4

Table 1 shows that in model simplification processing, when the model is simplified 50%, the proposed algorithm has obtained faster speed with facets shrinkage, the precision of the two algorithms has no significant difference; when model simplified proportion is more than 80%, this presented algorithm produces large triangle slices in the flat place of surface; when simplified rate is up to 90%, the details of model has been almost lost with QEM, the improved algorithm still keep highly similarity to original model, it shows that the algorithm can still generate high quality in the case of large proportion simplification. Observing hollow and heave on the cattle model in the process of simplification, we can find that the feature of model is vague in QEM when simplification ratio is more than 95%, while correspondingly obvious in presented algorithm. It shows that this algorithm can carry on different processing according model curvature change in different parts of the model. With smaller curvature changing, there is larger simplification degree, larger curvature changing with smaller simplification degree instead. This algorithm preserved original features better. The algorithm run slightly faster than QEM algorithm.

Summary

This paper puts forward a method of mesh simplification algorithm based on edge and surface folding, the curvature characteristics of the model vertex is introduced into the calculation of effective vertex weight value, and also triangular facet weight value at the same time, the facet with smaller weight value in two triangular facets adjacent the candidate edge is selected for folding. the experiment results have shown that this algorithm has a higher simplified quality of model, and can effectively keep original features model.

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