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3D Shape Retrieval Method based on Normal-Angle Histogram

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Abstract: This paper puts forward 3D model retrieval method based on normal-angle histogram. The method firstly makes the pretreatment for 3D model, and defines the calculation method of the normal at every vertex of the triangular mesh in 3D model and the included angle among the triangular meshes. Then it classifies the triangular mesh in accordance with the normal at three vertexes of the triangular mesh and the included angle among the triangular meshes, and divides the triangular mesh into four types as per the included angle whether acute angle or obtuse angle, constructs the shape distribution curve for every type of triangular mesh collection, obtains the similarity of two shapes by comparison of four shape distribution curves of 3D model, and accordingly realizes the similarity retrieval of 3D model. The test indicates that the retrieval accuracy rate and the retrieval efficiency of the algorithm are superior to other similar histogram algorithm.

Keywords: Normal; Angle histogram; 3D model retrieval

1 Introduction

With the continuous progress and development of the computer technology, 3D model software has been widely applied to the product design, analog simulation, animation film, online game and other fields, and more and more 3D models appeared in the enterprise, network and other places. Therefore, finding 3D model meeting the user design and using demand correctly among various 3D models and achieving 3D model retrieval system of the resource reusing become the hotspot research issues in 3D model field at present [1].

3D model retrieval can be two retrieval modes based on the attribute text and shape feature. The retrieval mode based on the attribute text demands the attribute marking and definition on 3D model manually. The retrieval method is realized simply, but possesses the defects in the following aspects. For the same shape, the information of the attribute marking can be different with the different markers. The retrieval user may not know which key words are used for retrieving the required shape. The attribute marking can be changed with the time, such as the change of the naming rules. It needs the additional manpower and material resources for the shape marking information. Due to these defects, the application effect of the retrieval mode based on the attribute text is not very good.

The retrieval based on the shape feature is to match the retrieval contents automatically in accordance with the actual shape of 3D model, and further can objectively express the shape feature of 3D model. Thus, this method is more effective than the retrieval mode based on the attribute text. The retrieval technology based on the shape feature can be divided into three classes as a whole [2]. The retrieval technology based on the image comparison extracts the characteristics quantity for 3D model, involving the optical field description method [3] and 2D outline drawing [4]. The retrieval technology based on the shape feature is to make retrieval through extracting the shape feature of 3D model, involving the shape histogram [5], weighting point set [6], influence descriptor [7], shape description framework based on density [8] and other methods. The retrieval technology based on the topological structure is to make retrieval through extracting the topological structure feature of 3D model, involving method based on Reeb diagram [9], method of expanding Reeb diagram [10], method based on topological link diagram [11], and method based on 3D skeleton diagram [12].

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For the triangular mesh shape, the expression of the normal at every vertex on the shape is very important. The literature [?] puts forward 3D model retrieval algorithm based on the radial included angle histogram of the polar radius. The algorithm firstly resolves a series of homocentric sphere adopted by the shape, calculates the collection attribute of the radial included angle for describing 3D model as for the point falling into every section, and finally constructs the histogram feature in combination with polar radius and radial included angle. This paper puts forward 3D model retrieval algorithm based on the normal included angle histogram. The method defines the included angle between 3D model vertex and triangular mesh patch, and then divides the triangular mesh into four collections in accordance with the value of the included angle at three vertexes of triangular mesh. It generates the histogram shape distribution curve of four collections, judges the similarity among shapes by comparison of four histograms of different shapes, and accordingly realizes the similarity retrieval of 3D model.

2 Shape Retrieval Method Based on Normal-angle Histogram

2.1 Mesh Expression of 3D Model

The curves and surfaces in CAD system are expressed accurately, but the internal expressive methods are different, so that the data among different CAD systems can not be exchanged and shared. In order to solve the problem, the scholars in the mechanical field adopt many neutral file formats (such as STL, STEP and VRML etc). Because different CAD softwares support these formats, CAD system can convert 3D model into the neutral file. STL file, as a typical mesh expression, is composed of the unordered space triangle, and is the linear approximation of the accurate shape. The file records the dispersed triangular patch information, and every patch includes 4 data items, i.e. the patch vertex coordinate and patch normal vector.

$$\begin{array}{ccc} n_x^{(i)} & n_y^{(i)} & n_z^{(i)} \\ p_{1x}^{(i)} & p_{1y}^{(i)} & p_{1z}^{(i)} \\ p_{2x}^{(i)} & p_{2y}^{(i)} & p_{2z}^{(i)} \\ p_{3x}^{(i)} & p_{3y}^{(i)} & p_{3z}^{(i)} \end{array}$$

$n_x^{(i)}, n_y^{(i)}, n_z^{(i)}$ indicates the external vector of the i triangular patch, $p_{kx}^{(i)}, p_{ky}^{(i)}, p_{kz}^{(i)}$ indicates 3D coordinate of the textitk vertex of the i triangular patch, $k \in [1,3], i \in [1,N]$, N is the patch quantity of the shape.

2.2 Pretreatment of 3D Model

For the shape analysis and matching for 3D model, the pretreatment is an indispensable step. Here the pretreatment mainly includes the triangular mesh simplification and scale normalization processing.

2.2.1 Mesh Simplification Processing

3D model has different expression methods, and 3D mesh shape expression is the most common one. Moreover, other expression methods can also be converted into the mesh shape easily. But for the 3D mesh shape, the surface vertex distribution is not always uniform, and accordingly causing a certain influence for the result of the retrieval algorithm. STL file is to express the shape by the triangular mesh shape. Thus, it can have different expression forms for the same shape, as shown in the following figure, i.e. two mesh expression forms of the same shape.

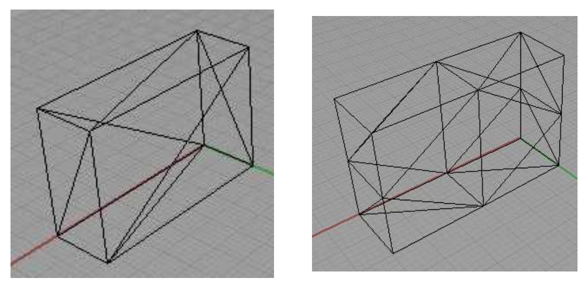

Fig. 1: Different Expression Forms of the Same Shape

For the expression forms of 2 shapes in Fig. 2, we can see that the collection of the point and area is the minimum for the expression mode of the first shape. Moreover, some points in the second shape can not indicate the convex-concave information of the shape, and the collection of the point and surface similar to the first shape will be gained after filtering these points.

In order to avoid the influence of different expression forms of points and surfaces of the similar shape on the algorithm, we consider firstly making the pretreatment process for all shapes, i.e. simplifying the shape to make the shape express concisely, and meanwhile highlighting the key feature of the object better. In the current mesh simplification strategy, the geometrical element deletion method is applied most extensively, involving the vertex deletion method, triangle folding method, and edge folding method etc. We adopt the triangular mesh shape simplification method [1] based on the vertex deletion to make the pretreatment for the shape. The basic though is to judge the type of every vertex, and calculate upon selecting different criteria in accordance with different types. In the case of meeting the establishment conditions of the criteria, the vertex is deleted, and the formed cavity is triangulated. The operation chart is shown as follows.

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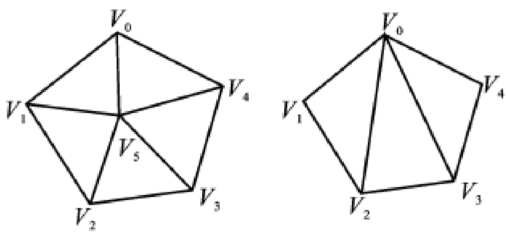

Fig. 2: Operation Chart of Vertex Deletion

There are two criteria of judging whether the vertex can be deleted. Firstly, if the normal vectors of all adjacent triangles of one vertex are the same, the vertex is deleted. Secondly, some two edges of the adjacent triangle are in a line, removing the point in the middle of the plane, and removing the unnecessary point on the edge. According to the algorithm, we make the simplification processing for the second shape in Fig. 2, and finally gain the shape expression similar to the first shape in Fig. 2.

2.2.2 Scale Normalization Processing

In order to guarantee that the scale of the shape can make comparison within the unified scope, it is necessary to carry out the normalization processing for the scale of the shape before the feature extraction, known as scaling transformation in the field of 3D model retrieval. The purpose of the scaling transformation is scaling the shape to a unified scale for processing. The method is the coordinate of every vertex of the shape multiplied by a scaling factor k, and the valuing method of k is shown as Formula (1).

$$k = \sqrt{\frac{k_x^2 + k_y^2 + k_z^2}{3}} \tag{1}$$

k_x is the mean distance from the surface vertex collection to YOZ plane. The calculation of k_y and k_z is similar to that of k_x. The calculation of k_x can adopt the method as shown in Formula (2).

$$k_x = \frac{1}{S}\sum_{i=1}^{M} s_i d_i \tag{2}$$

In the formula, S indicates the area and value of the triangular mesh patch in 3D model. s_i indicates the area of triangular patch i. d_i indicates the distance from the center of triangular patch i to YOZ plane. The calculation method of k_y and k_z is similar to this.

2.3 Calculation of Vertex Normal

The vertex normal vector is the important basis of calculating the equal differential geometric feature of Gaussian curvature and mean curvature of the shape. For the vertex normal vector estimation of the triangular mesh shape, Gouraud [13] expresses it by using the arithmetic mean value of the adjacent triangle normal vector of the vertex, and this method has the simple calculation. Taubin [14] puts forward estimating the vertex normal vector by using the weighted mean surface normal vector of the adjacent triangular area of the vertex, and the estimated result is used for the calculation of the vertex curvature. Grit et al [15] analyze the uncertainty influence of different division modes of polygon face on the calculation of the vertex normal vector, and put forward the calculation method based on the vertex angle weighting patch normal vector of the adjacent polygon. Shen et al [16] utilizes the area of the triangle and the normal vector of the product weighted triangle of the vertex angle at the vertex to acquire the estimated value of the vertex normal vector, and improves the curvature calculation method of Taubin by this method.

The vertex normal vector estimation method of Wang [17] gains preferable result in numerous experimental results. Therefore, we adopt the method of Wang to calculate the vertex normal vector, and the method can be indicated as:

$$\vec{n_v} = \frac{1}{Sum} \cdot \sum_{i=0}^{m-1} \left(\frac{\gamma_i}{Ai} \cdot \vec{n_i} \right) \tag{3}$$

In the formula, $Sum = \sum_{i=0}^{m-1} \frac{\gamma_i}{A_i}$, $\vec{n_v}$ is the normal vector in the vertex v. $\vec{n_i}$ is the normal vector of the triangle T_i in the adjacent domain of the vertex v. A_i is the area of the triangle T_i in the adjacent domain of the vertex v. γ_i is the vertex angle in the vertex v of the triangle T_i in the adjacent domain of the vertex v.

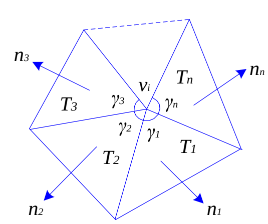

Fig. 3: Schematic Diagram of Vertex Normal Vector

2.4 Included Angle of Triangular Mesh and Vertex Normal

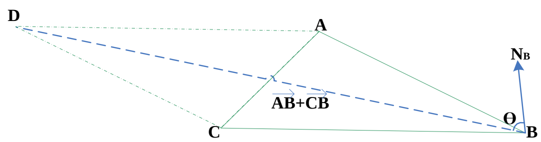

Fig. 4: Schematic Diagram of Included Angle of Vertex Normal and Triangular Mesh

Suppose the normal vector of the triangular vertex B is NB, as shown in the figure. In the figure, BD indicates the sum of the vector quantity AB and CB, and the vector quantity BD and the triangle ABC are on the same plane. The cosine of the included angle of the vector quantity NB and BD is:

$$\cos\theta = \frac{N_B \bullet}{|N_B| \times ||} = \frac{N_B \bullet (+)}{|N_B| \times |(+)|} \quad (4)$$

In the formula, the value range of θ is $[0, \pi]$.

2.5 Classification of Triangular Mesh

According to the included angle between the normal of three vertexes of triangular mesh and the triangular mesh, the triangular mesh can be divided into four classes:

1) Class I is the pure concave mesh, i.e. the included angle between the normal of three vertexes and the triangular mesh is the acute angle. The acute angle indicates that the triangular mesh around three vertexes and this triangular mesh constitute a concave curved surface, and reflects the concave feature of the shape.

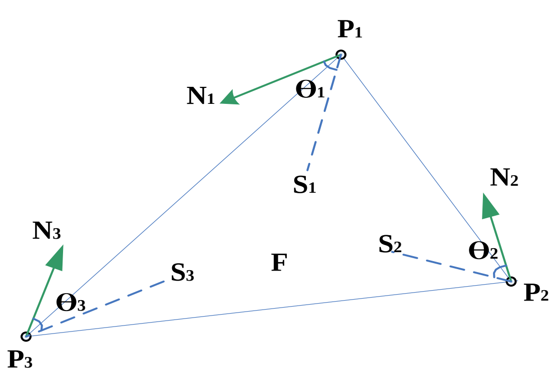

Fig. 5: Schematic Diagram of Pure Concave Triangular Mesh

2) Class II is semi- concave mesh, i.e. in the included angle between the normal of three vertexes and the triangular mesh, involving two acute angles and one obtuse angle. It indicates that the region related to two vertexes is the concave curved surface and the region related to the remaining one vertex is the convex curved surface in the region around the triangular mesh, and reflects the semi- concave feature in the shape.

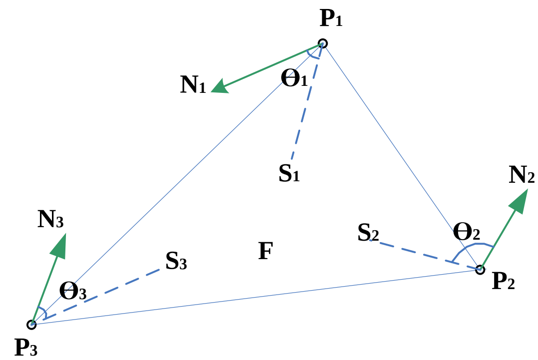

Fig. 6: Schematic Diagram of Semi- concave Triangular Mesh

3) Class III is semi- convex mesh, i.e. in the included angle between the normal of three vertexes and the triangular mesh, involving one acute angle and two obtuse angles. It indicates that the region related to two vertexes is the convex curved surface and the region related to the remaining one vertex is the concave curved surface in the region around the triangular mesh, and reflects the semi- convex feature in the shape.

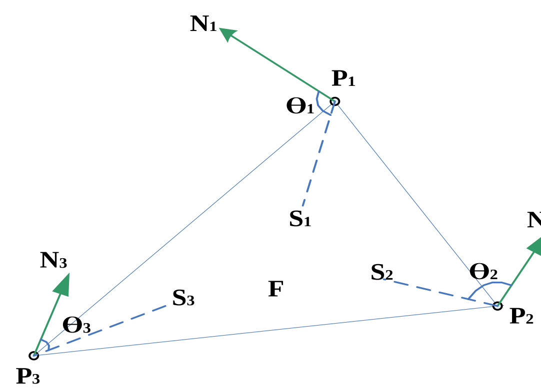

Fig. 7: Schematic Diagram of Semi-convex Triangular Mesh

4) Class IV is pure convex mesh, i.e. the included angle between the normal of three vertexes and the triangular mesh are the obtuse angles. It indicates that the region around the mesh and the triangular mesh constitute

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a convex curved surface, and reflects the convex feature in the shape.

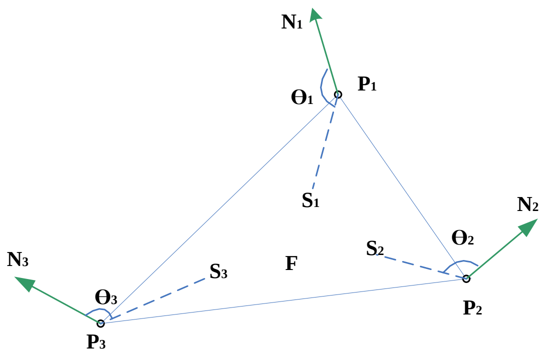

Fig. 8: Schematic Diagram of Pure Convex Triangular Mesh

Due to the simplification processing for the triangular mesh before calculating, the deletable vertex is deleted fully, and the included angle between the triangular mesh and the vertex normal will not have the situation of $\theta = \pi/2$. Table 1 shows the classification method of the triangular mesh patch in 3D model.

Table 1: Class Conditions of Mesh

Class	Conditions
Class I, pure concave	$\theta_1 < \pi/2$ and $\theta_2 < \pi/2$ and $\theta_3 < \pi/2$
Class II, semi- concave	$\theta_1 > \pi/2$ and $\theta_2 < \pi/2$ and $\theta_3 < \pi/2$ or $\theta_1 < \pi/2$ and $\theta_2 > \pi/2$ and $\theta_3 < \pi/2$ or $\theta_1 < \pi/2$ and $\theta_2 < \pi/2$ and $\theta_3 > \pi/2$
Class III, semi- convex	$\theta_1 > \pi/2$ and $\theta_2 > \pi/2$ and $\theta_3 < \pi/2$ or $\theta_1 > \pi/2$ and $\theta_2 < \pi/2$ and $\theta_3 > \pi/2$ or $\theta_1 < \pi/2$ and $\theta_2 > \pi/2$ and $\theta_3 > \pi/2$
Class IV, pure convex	$\theta_1 > \pi/2$ and $\theta_2 > \pi/2$ and $\theta_3 > \pi/2$

2.6 Formation of Histogram and Similarity Measurement

According to the class conditions in Table 1, the triangular mesh in the shape is classified, forming the collection I, II, III and IV. Carry out processing for the triangular mesh in each collection respectively, form the histogram, and adopt the mean value alignment method on the histogram for the normalization. The mean value of each collection is:

$$avg_k = \frac{1}{n_k}\sum_{i=0}^{n_k} area_i \tag{5}$$

In the formula, k value is the collection I, II, III and IV, indicating four collections of the triangular mesh respectively. avg_k indicates the mean area value of the triangular mesh in the k collection. n_k indicates the quantity of the triangular mesh in the k collection. $area_i$ indicates the normalization area of the triangular mesh.

After calculating the mean area in each collection, Formula (6) is deemed as the length unit of the histogram horizontal axis.

$$step_k = \frac{avg_k}{N} \tag{6}$$

In the formula, $step_k$ is the length unit of the histogram horizontal axis in the k collection. avg_k is the mean area value of the k collection. N is a constant, and valuing textitN=80 has preferable effect in this paper.

For the histogram h_1 and h_2 formed by the k collection of two shapes to be compared, the similarity measurement method is:

$$dis_k(h_1,h_2) = \frac{1}{m_k}\sum_{i=0}^{m_k} |h_{1i} - h_{2i}| \tag{7}$$

In the formula, m_k=max(m_{k1},m_{k2}). m_{k1} and m_{k2} are respectively the quantity of the interval $step_k$ in the k class of histogram of two compared shapes. In order to realize the similarity comparison of the histogram by using Formula (7), the zero padding processing will be made for the histogram with less interval quantity, and the interval quantity of two histograms will be m_k. The purpose of dividing by m_k is to make the comparison result among the shapes independent of the influence of the interval quantity of the distribution curve.

The similarity measurement between Shape A and Shape B is:

$$Sim(A,B) = \sum_{i=1}^{4} \omega_i dis_i \tag{8}$$

In the formula, ω_i is the weight of the different scale of the corresponding collection respectively.

$$\omega_i = \frac{n_{1i} + n_{2i}}{n} \tag{9}$$

n_{ik} is the quantity of the triangular mesh in the k class collection of the i shape. n is the total quantity of the triangular mesh in two shapes.

3 The Experimental Results

Borland Delphi 7 is regarded as the integrated development environment, in combination with Matlab 6.5, the algorithm proposed in this paper is realized, and also verified on ESB (Engineering Shape Benchmark) [18] established by Purdue University. The experiment adopts PC computer, Intel (R) Core 2 Duo 2. 20GHz CPU, 3G memory.

ESB contains 866 engineering models of STL format. We consider any one model as input, and intend to retrieve the similar shape in the model library. The

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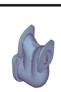
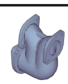
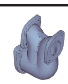
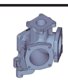
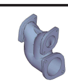
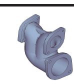
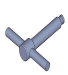
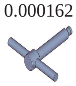
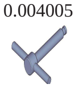
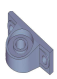
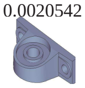
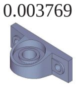
algorithm described in this paper regards STL format of the model as the retrieval input. Table 2 lists the previous retrieval results, and the digit indicates the similarity of the retrieved model and the input model. According to the above description, we know that the similarity closer to zero will have higher similarity level.

Table 2: Retrieval Result of Some Models

Retrieval Model	1	2	3	4	5
	 0.0000429	 0.000162	 0.000774	 0.004005	 0.004027
	 0.0020542	 0.003769	 0.004417	 0.004777	 0.005371
	 0.0022806	 0.002354	 0.002767	 0.002897	 0.003031

The statistics for the retrieval time and effectiveness of different retrieval inputs can gain the average behavior of the algorithm. Make statistics for the model in allusion to ESB library, and synthesize to gain the average behavior of the algorithm in the entire ESB library. Carry out the precision ratio – recall ratio curve, and make the comparison among other shape retrieval algorithms (light field descriptor method (VS Method) [3], D2 shape distribution (D2) [19], D-IA shape distribution based on simplification (DIA Method) [20], and the comprehensive method based on geometry and statistical information (GRSI Method)[21]), as shown in Fig. 9.

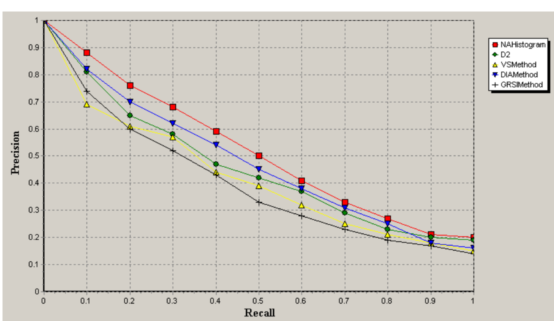


Fig. 9: S Recall ratio – precision ratio curve of different retrieval methods

Make the comparison between the normal angle histogram and some similar histogram methods. These similar histograms include the angle distance feature (AD), extended Gaussian image (EGI), and D2 shape distribution method (D2) etc. These four methods adopt the form of histogram to describe 3D model features. Table 2 compares the retrieval accuracy and efficiency of four retrieval algorithms. See References for the meaning of FT, ST and NN [22]. It shows that the method based on the normal angle histogram has the obvious improvement in the retrieval accuracy rate, but does not have the obvious increase in the aspect of the computation complexity.

Table 3: Quantitative Comparison of Different Retrieval Algorithms

Feature	NN (%)	FT (%)	ST (%)	Time (s)
AD	39.2	21.3	30.5	0.32
EGI	37.5	15.3	27.8	0.18
D2	31.1	15.8	23.5	0.24
Algorithm in this paper	65.3	40.2	51.8	0.21

4 Conclusion

This paper gives a retrieval algorithm of describing 3D model by using the shape distribution diagram of four normal angles, classifies the triangular mesh through the included angle of the vertex normal in 3D model and the triangle patch relevant to the vertex, expresses 3D model as the shape distribution curve of four normal angles, compares the similar distribution curves of the compared shape respectively, and gain the final similarity result of two shapes for four comparison results by the method of weighting summation. The algorithm in this paper preferably seizes the topological structure of 3D model through the proper classification of the triangular mesh, so the retrieval effect is enhanced greatly. The algorithm in this paper is applicable to 3D model with the entity attribute, and is fully applicable to the shape without the entity attribute. The retrieval speed is fast. The experiment result shows that it possesses the extensive practicability and good application value.

The algorithm adopts the normal angle histogram as the feature descriptor of 3D model, so the feature descriptor has good stability for various geometric transformations (translation, rotation and scaling). The histogram curve additionally generated can be serially saved as the index, and provide the secondary retrieval with the direct result for utilization, so as to improve the speed and efficiency of the retrieval.

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