World Academy of Science, Engineering and Technology
International Journal of Mathematical and Computational Sciences
Vol:3, No:9, 2009

# 3D Model Retrieval based on Normal Vector Interpolation Method

Ami Kim, Oubong Gwun, and Juwhan Song



***Abstract*—**In this paper, we proposed the distribution of mesh normal vector direction as a feature descriptor of a 3D model. A normal vector shows the entire shape of a model well. The distribution of normal vectors was sampled in proportion to each polygon's area so that the information on the surface with less surface area may be less reflected on composing a feature descriptor in order to enhance retrieval performance. At the analysis result of ANMRR, the enhancement of approx. 12.4%~34.7% compared to the existing method has also been indicated.

***Keywords*—**Interpolated Normal Vector, Feature Descriptor, 3D Model Retrieval.

## I. Introduction

RECENTELY, the development of modeling tools and scanning devices has enabled easy creation of 3-dimensional data sets at a low cost, and the development of Web has enabled access to and collection of 3-dimensional models. 3-dimensional models are expanding their use to various fields such as industrial design, virtual space realization, medical imaging, molecular biology, cultural remains restoration, etc. This requires accurate shape analysis and effective management and search of 3-dimensional models.

Generally, 3-dimensional models compare and retrieve extracted descriptors that can express model shapes best. Extraction of shape descriptors is realized through 4 steps such as preprocessing, model abstraction, digitization and descriptor creation. 3-dimensional models are preprocessed to normalize rotation, translation and scale so that shape descriptors may not show different features to simple changes such as model directions or sizes, first. Then, models are abstracted into geometrical elements of surfaces, voxel, images projected 2-dimensionally, etc. Models abstracted like this are used directly as a descriptor or digitized using various methods such as sampling, discrete Fourier transform (DFT), wavelet transform, etc. Feature descriptors are expressed as an element of vector space with a proper metric to enable comparison between models, created through summary in a statistical way such as a histogram, distributional map, etc. to show appearance frequency by examining specific features of models, or created in a graph composed of nodes and edges to express structural shapes of models.

Various researches for extracting the most suitable feature descriptors are under active progress. The 3D shape-based descriptors proposed by existing researches include direction of surface normal distribution, surface curvature, EGI(Extended Gaussian Image), 3D Hough Transform, etc.

The searching method, using the direction of a surface normal vector, proposed by Paquet[4] composes a two-variable histogram by obtaining the angle between the first two principal axes and the surface normal vectors of all polygons. This method contains a great deal of information on surfaces, but is very sensible to LOD(Level Of Detail).

Zaharia/Preteux[10]-[12] suggested a feature descriptor of shape spectrum, which shows the distribution of shape indices for the entire surface of a 3-dimensional model in a 1-dimensional histogram. A shape index uses a polar representation angular coordinate system of principal curvature vectors. Depending on values of shape indices, the shape of surfaces can be expressed basically as spherical cup, rut, middle saddle, ridge, and spherical cap. This is robust against geometric transformation and scale transformation. However, basic shapes of surfaces are divided depending on difference between two curvatures and its sign, not considering that even a mesh with the same shape index value can have a different curvature from neighboring planes. Therefore, shape changes of 3-dimensional models pursuant to the size of principal curvature cannot be reflected.

The EGI[3] proposed by Horn maps a surface normal vector of a model to a point corresponding to its direction on a unit sphere. A weight is given to each point on a unit sphere in proportion to the area of a surface containing the normal vector. Its processing speed is fast and its conformity is efficient, but models whose shapes are different from each other and are not convex have the same EGI, which weakens discrimination.

This paper proposes a new feature descriptor for 3D model retrieval. An interpolated normal vector distribution of polygons forming a 3D model is used as a feature descriptor. The configuration of this article is as follows. Section II describes the extraction process of the proposed feature descriptor describes a method of measuring similarity in models, Section III compares and analyzes the experiment results of existing algorithms and proposed algorithms, and

Ami Kim is with the Division of Electronics and Information Engineering, National University of Chonbuk, Jeollabuk-do, Jeonju-si, South Korea (e-mail : iamami@paran.com).

Oubong Gwun is with the Division of Electronics and Information Engineering, National University of Chonbuk, Jeollabuk-do, Jeonju-si, South Korea (e-mail : obgwun@chonbuk.ac.kr).

Juwhan Song is with School of Liberal Art, University of Jeonju, Jeollabuk-do, Jeonju-si, South Korea (e-mail : jwsong@jj.ac.kr).

Section IV derives a conclusion and a future research project.

## II. Extraction of a Feature Vector

The directional distribution of normal vectors as a feature descriptor is decided into two kinds such as a normal vector of polygons forming a 3-dimensional model and a normal vector of boundaries interpolated from normal vectors of nodes. In this case, the directional distribution of interpolated normal vectors includes the connectional and positional information of each surface, so it can enhance discrimination as compared to existing methods simply considering the directional distribution of normal vectors. The direction of a normal vector is projected on 80 reference surfaces(patch, cell) quartering a regular icosahedron, its distribution is obtained by reference surfaces, and then a model of quality and a similarity of each model are measured.

Fig. 1 is a block diagram showing an outline of how to extract feature descriptors suggested by this article.

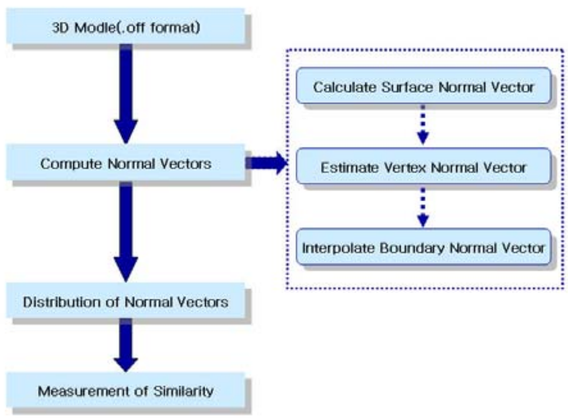



Fig. 1 Diagram of the extraction of proposed feature descriptor

### A. Obtaining the Normal Vector

Obtain a normal vector for all polygons. For a surface normal vector, calculate the inner product of a vector connecting the center of a cell and the center of a polygon and a normal vector of polygons respectively.

Then, obtain a normal vector of nodes. Obtain a normal vector of boundaries by interpolating this. For the interpolation of normal vectors, use bidirectional linear interpolation. That is, apply interpolation by x, y, z components of a vector. In Fig. 2, for n6, obtain n4 by interpolating n1 and n3 in the y-axis direction first, and then obtain n5 by interpolating n2 and n3. The normal vector inside the indicated triangle, n6, is obtained by interpolating n4 and n5 in the x-axis direction.

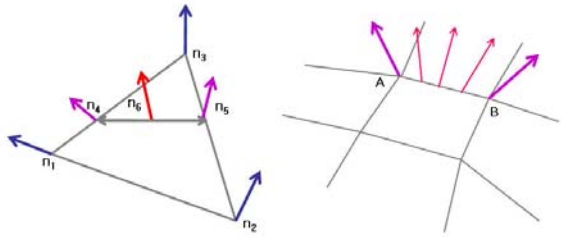



Fig. 2 Bilinear interpolations

Interpolated normal vector in triangle is created with the distribution of point normal vectors, that points are sample points in proportion to its area in triangle. It has an important influence on search performance by determining the characteristics of a model whether the points used as a sample are evenly distributed on a surface or not [8]. A 3D mesh model is expressed with vertex coordinates and connection information between them. The number of vertexes differs depending on models, and the number and size of surfaces also differ. It is necessary to consider this point in creating points used as a sample. In general, the PRNS(Pseudo-Random Number Sequence)[9] used for point sampling as a disadvantage that points are not evenly distributed on a surface. Accordingly, this article handles it such that the number of sampled points may be proportional to the area of a polygon model by deforming the method proposed by Osada [2].

After calculate the area of each triangle, accumulate and then save it separately. In order to create a point on a triangular surface, comply with the following process. Select a triangle in proportion to the area by generating a random number between 0 and the total accumulated area value. With respect to the selected triangle T(A, B, C) with a vertex (A, B, C), create two random numbers between 0 and 1, $r_1$ and $r_2$, and then create a point within the triangle using (1).

$$p = \left(1-\sqrt{r_1}\right)A + \sqrt{r_1}(1-\sqrt{r_2})B + \sqrt{r_1}r_2 C \qquad (1)$$

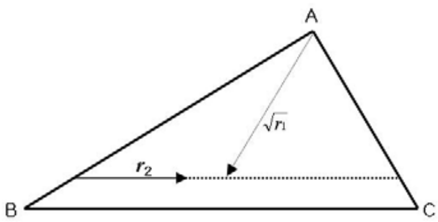



Fig. 3 Sampling a random point in a triangle

Interpolating normal vectors can enhance discrimination because a spatial shape feature is reflected by considering the connection relationship between meshes.

### B. Construction of Histogram

Each surface of a regular icosahedron is divided into 4 triangles in order to create a directional histogram. All of the divided 80 cells become reference surfaces, with the same area and shape, being more elaborate than 20 surfaces to have each enough angular resolution.

After obtaining a normal vector for every mesh and then project this vector on the surface in the nearest direction among 80 surfaces. Obtain a reference vector for every surface to be projected. With the center of mass on each surface to be projected as the terminal point of a reference vector and with the center of mass of each polygon as a initial point, obtain the angle between it and a normal vector at this point, project the normal vector of the surface with the smallest angle and the normal vector interpolated at the sampled point inside the surface, on the polyhedron, and create a directional histogram with its quantity.

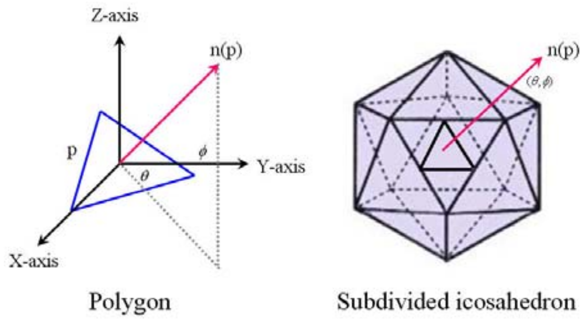



Fig. 4 Mapping from normals to the subdivided icosahedron

### C. *Measurement of Similarity*

For the measurement of similarity for a 3D model firstly, extract the distribution of normal vectors for each model and then save it in a database. The measurement of similarity uses the $L_1$-norm of the histogram of a model selected through an inquiry and the normalized and compared histogram.

The number of samples was set differently depending on the number of polygons composing a model, so the values of bins have diverse ranges depending on histograms. Therefore, the representative values of each bin in a histogram are set and normalized in a ratio with respect to the total frequency.

## III. Experiment Results and Evaluation

The retrieval System is implemented by Visual C++ 2008 in personal computer consists of 4GB DDR2 RAM and Intel core 2 duo E6700 2.66GHz CPU. Experiment data is used a shape benchmark database provided by Princeton University(PSB) [10]. Search data is comprised of a total of 15 classes and 456 models. Each model is consist of polygonal mesh and has only numerical data of vertex and face. The file format of this model is off. Table I is the experimental model class and the number of models included in class.

TABLE I
Model Classes Used in the Experiment

| Class | No | Class | No |
|---|---|---|---|
| biplane | 28 | human | 94 |
| commercial | 20 | human_arms | 41 |
| computer_monitor | 9 | military_tank | 16 |
| face | 31 | race_car | 14 |
| fighter_jet | 98 | sedan | 18 |
| fish | 15 | spider | 11 |
| flying_bird | 13 | sports_car | 17 |
| head | 31 | | |

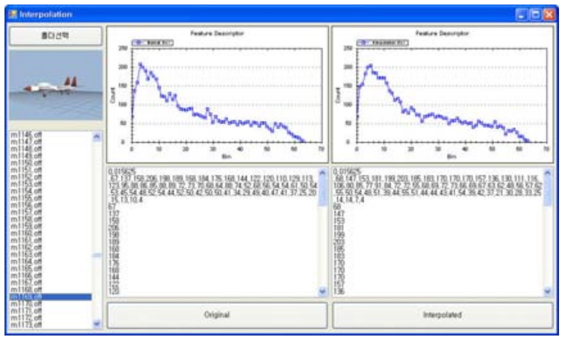



Fig. 5 Comparison original normal with interpolated normal

Of the existing algorithms to be compared, SND(Surface Normal Distribution) and the algorithm using surface normal vector information uses EGI.

The result of normal vector interpolation experiment is represented by average normalized modified retrieval rank(ANMRR)[11]. ANMRR is a normalized rank equation and its value is distributed from 0 to 1. Fig. 6 shows the comparison of retrieval results.

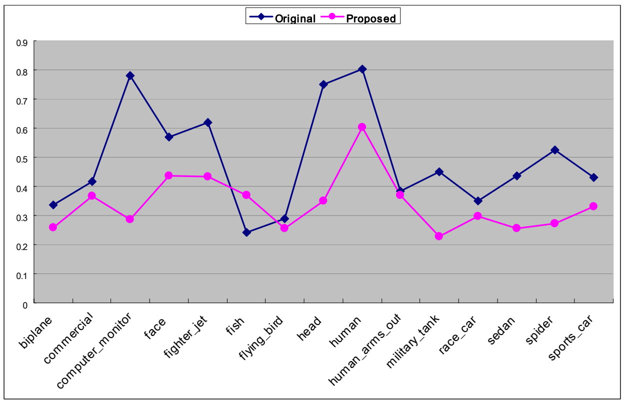
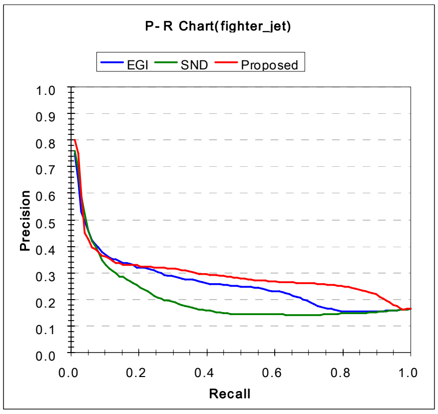



Fig. 6 ANMRR retrieval results of interpolation method

The retrieval performances are compared using precision and recall. The results of performance evaluation for 4 algorithms with respect to the classes of PSB can be shown with a precision and recall chart like Fig. 7.



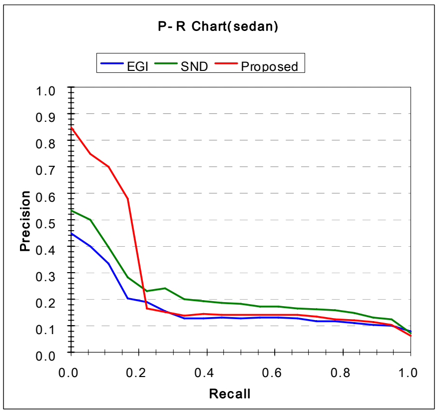




Fig. 7 Precision-Recall chart

As a result of precision-recall analysis, the algorithm suggested by 14 classes of the 15 classes showed better results than existing methods.

## IV. Conclusion

This paper proposed the distribution of mesh normal vectors pursuant to their directions as a feature descriptor of a 3D model. A normal vector shows the entire shape of a model well. The distribution of normal vectors was sampled in proportion to each polygon's area so that the information on the surface with less surface area may be less reflected on composing a feature descriptor in order to enhance retrieval performance. As a result, better performance was shown as compared to the existing algorithms.

At the analysis result of ANMRR, the enhancement of approx. 12.4%~34.7% compared to the existing method has also been indicated. Consequently, in the case when the directional information of the normal line has been selected as the feature descriptor, perfect consistency of rotation for the model is difficult to obtain. The plan to complement this is under consideration and the study is under way for the creation of new feature descriptor.

## References

[1] Ryutarou Ohbuchi, Takahiro Minamitani, Tsuyoshi Takei, "Shape-Simility Search of 3D Models by using Enhanced Shape Functions", *IJCAT*, Vol. 23, No. 2/3/4 pp.70-85, 2005.
[2] Eric Lengyel, Mathmetics for 3D Game Programming and Computer Graphics Second Edition, 2004.
[3] YS Joo, Comparison of Polyhedra and Level Sets as Geometry Reconstruction Models, Segang University, 2003.
[4] Benjamin Bustos, "Feature-Based Similarity Search in 3D Object Databases", *ACM Computing Surveys*, Vol. 37, No. 4, pp.345-387, 2005.
[5] Ding-Yun Chen, Xiao-Pei Tian, Yu-Te Shen, Ming Ouhyoung, "On Visual Similarity Based 3D Model Retrieval", *Proceedings of EUROGRAPHICS*, Vol. 22, 2003.
[6] Robert Osada, Thomas Funkhouser, Bernard Chazelle and David Dobkin, "Shape Distributions," *Transactions on ACM Graphics*, Vol. 21, pp.807-832, 2002.
[7] Philip Shilane, Michael Kazhdan, Patrick Min and Thomas Funkhouser, "The Princeton Shape Benchmark“, *Proceedings of the Shape Modeling International*, pp. 388-399, 2004.
[8] M Lu, H Luo, J S Pan, "3D Model Retrieval Based on Vector Quantisation Index Histograms", *Journal of Physics*, pp.437-41, 2006.
[9] US Ju, Computer Graphics learning by OpenGL, 2006.
[10] T. Zaharia and F. Preteux, “Results of 3D Shape Core Experiment,” ISO/IEC JTC1/SC29/WG11 M6315, 2000.
[11] T. Zaharia and F. Preteux, “3D Shape Core Experiment: Semantic Versus Geometric Categorization of 3D Mesh Models,” ISO/IEC JTC1/SC29/WG11 M6104, 2000.
[12] T. Zaharia and F. Prêeux, “3D Shape-based Retrieval within The MPEG-7 Framework”, Proc. SPIE Conf. on Nonlinear Image. *Processing and Pattern Analysis XII*, vol.4304, pp.133-145, 2001.