3D Model Search Using Integral Spin Images

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ABSTRACT

The increasing number of three-dimensional data on the web and huge 3d-model databases in special applications give rise to the problem of its retrieving. At the same time this issue is one of the most popular and complex tasks in computer vision theory. The main challenge is to develop efficient and robust matching algorithm that works with arbitrary polygonal models. One of approaches for model matching is based on global surface descriptors, which represent the shape of the whole 3D model surface in compact and informative manner. We present new global surface descriptor called integral spin image which utilize the concept of popular local surface descriptors spin images. We also propose special 3D model normalization method for integral spin image estimation. We show that the new model matching algorithm based on integral spin images provides favorable shape similarity measure and can be successfully used in 3D model search systems.

Keywords

Integral Spin Image, 3D Model Search, 3D Model Matching, 3D Model Normalization.

1. INTRODUCTION

Searching 3D databases is challenging task in computer science. The main problem is to develop 3D model matching method. Direct matching of two models is impossible because they have no similar scale, position and orientation in general. That's why integral representation of 3D shape (global surface descriptor) is firstly computed for each model. Then these representations are matched by one of statistics methods (e.g. correlation coefficient). In this way the work of 3D model retrieval system can be divided into two phases: offline and online. Offline phase includes global surface descriptor estimation for each model from the database. Computation of the descriptor for request model, matching and generating the answer are going online. The scheme of the retrieval system is shown at Figure 1.

Recently, a lot of researches have investigated the problems of 3D model retrieval. Principle aspects of 3D model search systems and good classification of 3D model retrieval methods are given in [Tan04a]. Comprehensive review of 3D shape descriptors, which can be used in different applications (recognition, retrieval, clustering, classification, etc.) is presented in [Zha04a]. Applications and technologies for shape-based retrieval and analysis of 3D models are explored in [Fun05a]. An example of 3D model retrieval technique is proposed in

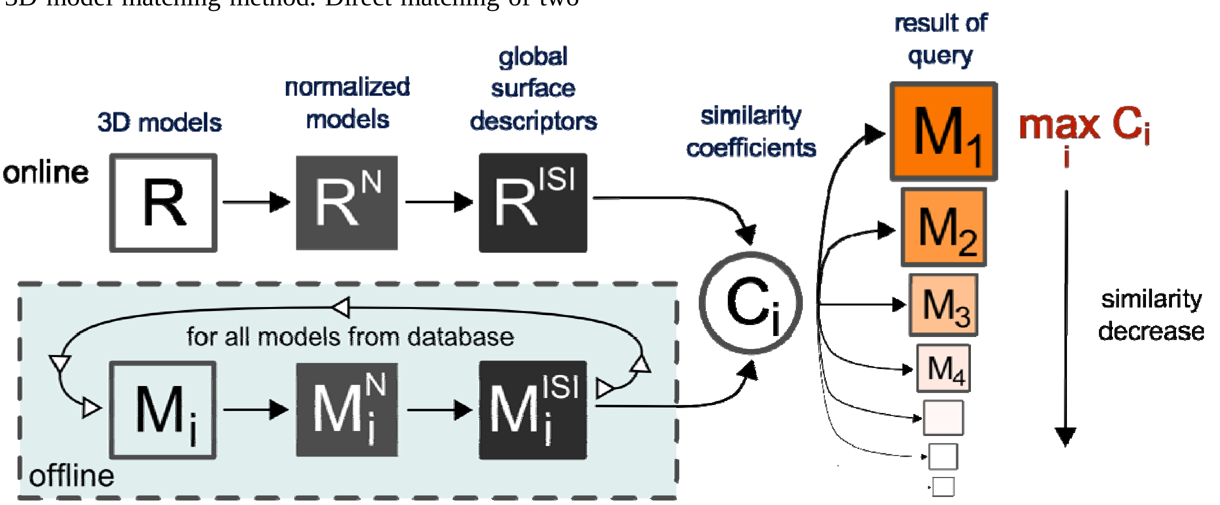

Figure 1. Scheme of 3D model search with global surface descriptors estimation.

[Vra00a]. The authors utilize feature vector as shape descriptor. The feature vector consists of distances from the center of 3D model to the specific points on the surface. Principle component analysis is used to normalize 3D model before descriptor estimation. Methods based on 3D shape histograms are described in [Ank99a, Lu10a]. In [Vra01a] authors introduce shape descriptor based on 3D discrete Fourier transform. Special shape matching technique is proposed in [Liu08a]. PCA method and ICP (Iterative Closest Points) algorithm are both firstly applied to 3D models. Similarity between two models is estimated by using difference sum of squares function. To improve retrieval performance authors of [Kaz03a] deal with spherical harmonics representation of 3D shape descriptors.

In this paper we describe new method for searching 3D databases using integral spin images which are global surface descriptors based on popular local surface descriptors spin images [Jon99a, Jon97a]. Integral spin image requires base point and vector for its computation. Integral spin image is also scale dependant descriptor. So the specific model normalization should precede integral spin image estimation.

The paper is organized as follows. In section 2 we recall the concept of ordinary spin image. Section 3 is devoted to integral spin image definition and the peculiarities of its computation. In section 4 we investigate 3D model normalization procedure. Integral spin image matching algorithm is proposed in section 5. Some results of proposed method are also in that section. We conclude in section 6.

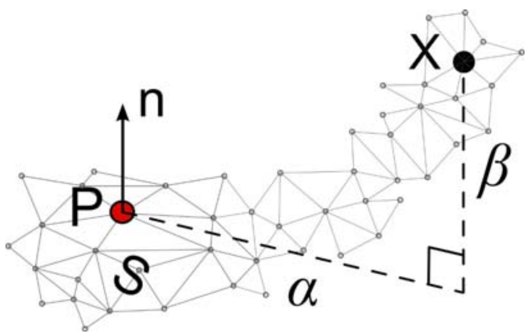

Figure 2. Relative cylindrical coordinates *α* and *β*. P – base point, n – normal vector, X – model point, S – model surface fragment.

2. ORDINARY SPIN IMAGE

Spin image is local surface descriptor, so it describes the shape of relatively small part of model surface. It is computed locally in one of surface points (we call this point *base point*). The idea of spin image is based on association of base point with cylindrical coordinate system without polar angle. For each point from a locality of base point the relative cylindrical coordinates α and β are estimated (Figure 2). The formulas for α and β are

$$\alpha = \sqrt{\|\mathbf{X}-\mathbf{P}\|^2 - (\mathbf{n}\cdot(\mathbf{X}-\mathbf{P}))^2}\ ,\ \ \beta = \mathbf{n}\cdot(\mathbf{X}-\mathbf{P})$$

The locality of base point, bounded with $\alpha_{\max}$ and $\beta_{\max}$, is divided on bins by the values of α and β. The points with similar relative coordinates fall into the same bin. The bins have the shape of three-dimensional rings (Figure 3). The position of each

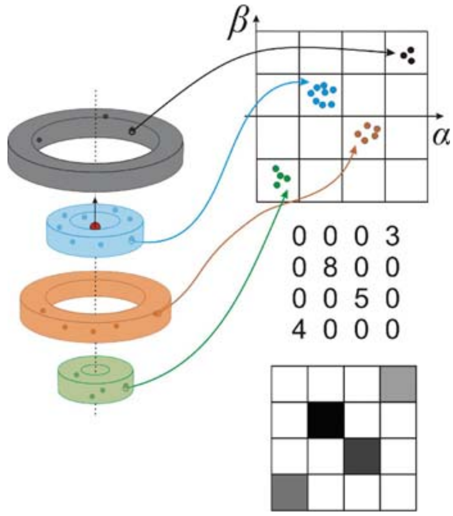

Figure 3. Spin image bins. The points with similar relative coordinates fall into the same bin (3D ring) – the cell of two-dimensional integer matrix. Graphical representation of spin image is grayscale image. Each pixel intensity is defined by corresponding matrix element.

bin in the space is set by two integer indices. In this way spin image is two-dimensional matrix of bins. The value of its element is equal to the number of points in corresponding ring.

Spin images have very good descriptive features and are invariant to translation and rotation. They are successfully applied in surface registration, matching and object recognition [Cor01a, Jon99a, Jon97a].

3. INTEGRAL SPIN IMAGE

The concept of spin image can be expanded to create new global surface descriptor. In the case of global descriptor we should not restrict the locality of base point and use all of the model points (Figure 4).

Computation of ordinary spin image requires the coordinates of base point and the normal vector in this point. The question is which point and vector should we use to construct global descriptor *integral spin image*. This is very important moment because global surface descriptors must be computed the same way for all 3D models. Thus completely identical models have the same global descriptors. This condition is fundamental in matching method

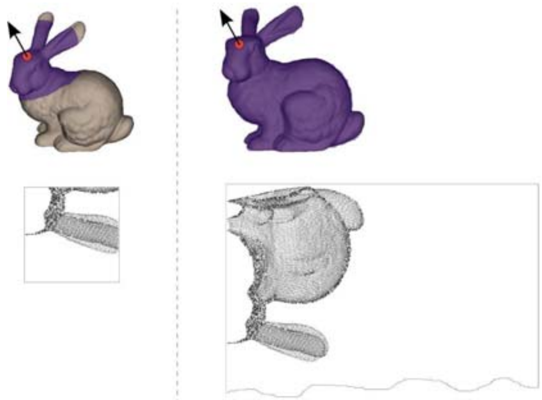

Figure 4. Ordinary (left) and integral (right) spin images. The last describes the whole model shape, while the former – only the part.

implementation. Computation of base point and vector for integral spin image should rely on model global features, such as centroid, principal axes, etc. Another problem which leads to matching error is different scale of 3D models. Optimal scaling should also precede descriptor computation. Detailed description of such 3D model normalization which includes scaling and base point and vector computation is in the next section.

After normalization integral spin image can be estimated. It is going the same way as in the case of ordinary spin image, except only that we use specific base point and vector and that the locality of base point is defined such way that each model point has to be inside it. So relative coordinates are computed for each point of a model and therefore integral spin image describes the shape of the whole model surface. The benefits of using the concept of spin image while constructing global surface descriptors are good descriptive features, small computational cost and availability of efficient and easy matching method. Matching algorithm is investigated in section 5.

4. NORMALIZATION

3D model normalization for integral spin image estimation include optimal scaling and base point and vector computation. Integral spin images of normalized models can be directly matched to define similarity of corresponding 3D models.

All normalizing operations can be executed independently from each other. Moreover normalization for single model runs without any knowledge about all other models. This fact allows preliminary normalization and descriptor estimation for all models from 3D database. At the request time it remains only to process one model and to match its descriptor consequently with descriptors of all models from database.

Before normalization procedure execution it is vastly necessary the model points to be uniformly distributed along the surface. We use the method for surface resolution control proposed in [Jon97a]. It is one of surface simplification algorithm. The main benefit of this method is minimal change of the shape after model surface processing.

4.1. Optimal scaling

Two models (two 3D point clouds) have optimal scale if each is normalized to have mean variance equal to one. This statement is proved in [Kaz04a]. In this way it is easy to compute the optimal scale factor for arbitrary point set $P=\{p_1, p_2, ..., p_n\}$.Given centered (centroid is in the origin) point set P mean variance of it is

$$D=\frac{1}{n}\sum_{i=1}^{n}\|p_i\|^2 .$$

The optimal scale factor is defined as

$$s=\frac{1}{\sqrt{D}} .$$

Multiplication of each point coordinates and the scale factor results in optimal scaling of corresponding model.

4.2. Base point

In the case of ordinary spin image base point is one of model points. Spin image is constructed around this point and describe the shape of small surface part (the locality of base point). Usually spin images are computed for all or for a subset of model points. As an example, for the purpose of surface registration spin images of one surface are consequently matched with all spin images of other surface. Then the best correspondences between points of these surfaces are established. The corresponding points are used to define the best transformation of one surface to another. In 3D model retrieval system integral spin image for each model should be computed only once around single base point. Thus base point should be defined for each model in a similar way. It is advisable to define base point for integral spin image as centroid of 3D model (mean of all model points). Obviously, similar models have similar positioned centroids. So, integral spin images constructed in these centroids with proper vector are also similar. The next subsection is about the method for choosing of the proper base vector.

4.3. Base vector

Ordinary spin image constructs around base point, which is one of model points, and normal vector in base point is used for relative coordinates computation. In the case of integral spin image base point doesn't have normal vector. The way to define vector for integral spin image estimation (we call this vector *base vector*) is to utilize principal axis of 3D point cloud which represents a model. Popular method for that is Principal Component Analysis (PCA). In this method principal components computation is reduced to estimation eigenvectors and eigenvalues of input data covariance matrix. In our case as input we have 3D model represented by point cloud. Given centered point set in three-dimensional space $P = \{p_1,..., p_n\} \subset R^3$ the element of covariance matrix C is

$$C_{ij} = \frac{1}{n-1}\sum_{k=1}^{n} p_k^{(i)} * p_k^{(j)} \ ,$$

where $p_k^{(i)}$ and $p_k^{(j)}$ are i-th and j-th coordinates of point p_k. C is square symmetric matrix of dimension three. Eigenvectors of this matrix forms orthogonal vector system and correspond to model point distributions along each space coordinate. Thus similar 3D models have similar principal axes. As base vector it is favorable to choose eigenvector of covariance matrix C which corresponds to the largest eigenvalue. This approach is robust enough and always results in proper base vector estimation.

5. MATCHING

Integral spin images computed after normalization procedure are in fact two-dimensional integer matrices. Since these global surface descriptors contain information about the shape of the whole 3D model surface, similarity of the descriptors means similarity of corresponding models. The simplest and at the same time the most efficient method for matching such kind of data is correlation measurement. It is sufficient to use linear correlation coefficient estimation. Several model pairs from Princeton Shape Benchmark 3D database [Pri04a] with its linear correlation coefficients are illustrated at Figure 5.

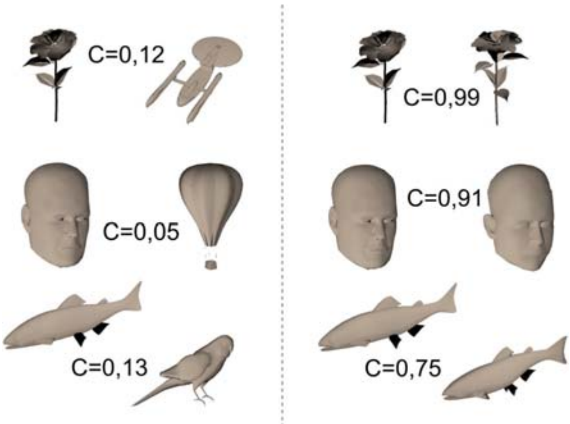

Figure 5. Pairs of models with different shape (left) and pairs of similar shape (right). C is linear correlation coefficient estimated for integral spin images of corresponding models.

The matching algorithm well discriminates different 3D models and allow proper retrieving of models from database with the shape similar to request model.

6. RESULTS

We used Princeton Shape Benchmark 3D database for experiments. The database contains 1815 models. We manually classified models by shape to execute precision/recall test. For example, we have 100 models of humans and 16 models of birds. The result of the test is given in Figure 6.

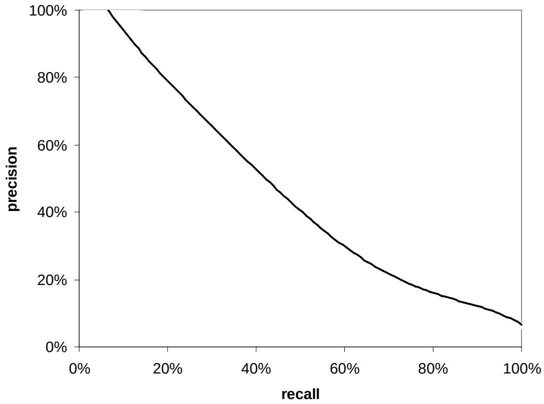

Figure 6. Average precision/recall of queries for 3D models using integral spin images as global surface descriptors.

This test was executed on ordinary PC. On average, the time needed for request is less then 1 second.

7. CONCLUSION AND FUTURE WORK

Proposed global surface descriptors both possess descriptive and efficient features of its local progenitors and are favorable enough for integral representation of 3D model shape. It's impossible to explicitly compute the integral spin image, as a result 3D model normalization procedure is required. Developed procedure results in robust, efficient and optimal model normalization. Integral spin image matching algorithm based on linear correlation coefficient well defines corresponding models with similar shape and executes in admissible time. As for future work, we plan to enhance our global surface descriptors by using of modified spin images and give our retrieval system the ability of 3D database indexation and anisotropic models handling. Comparing our proposals with other relevant methods and on a larger dataset is another main direction of our research.

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