

## View-based 3D model retrieval with probabilistic graph model

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### ABSTRACT

In this paper, we present a view-based 3D model retrieval algorithm using probabilistic graph model. In this work, five circle camera arrays are employed, and five groups of views are captured from each 3D model. Each captured view set is modeled as a first order Markov Chain. The task of 3D model retrieval is defined as a probabilistic analysis procedure, and the comparison between the query and other 3D models is changed to compute the conditional probabilities of 3D models in the database given the query model. The purpose to search 3D model is to find the maximal a posteriori probability of the models in the database given the query model. Then, we present a solution to estimate the conditional probabilities. The proposed 3D model retrieval algorithm has been evaluated on the NTU 3D model database. Experimental results and comparison with other methods show the effectiveness of the proposed approach.

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### 1. Introduction

The development of 3D rendering and visualization technologies has led to huge and ever-growing databases of 3D models. Compared with 2D images, 3D models can convey more information. The fast growth of 3D model archives necessitates the progress of 3D model retrieval techniques.

The purpose of 3D model retrieval is to design algorithms computing similarities between the query model and models in the database efficiently and effectively [3]. Recently, many literatures [1,2,8,9,11,15,18,19] focus on 3D model retrieval. More effective algorithms [22,23] are proposed recent years.

There are totally three categories of 3D model retrieval algorithms [20]: low-level feature-based methods, high-level structure-based methods, and view-based methods.

Low-level features describe the geometric moment [16], surface distribution [13], volumetric information [21], and surface geometry [6,7,14,17] of 3D models. Many low-level features are based on statistical methods, and 3D model retrieval depends on the low-level feature comparison.

High-level structure-based methods [20] describe the relationship among different parts of the 3D model.

In recent years, the concept of “light field” brings the view-based 3D model description methods. View-based methods [4] represent 3D models using a number of (binary) images, and 3D

models are described by a set of 2D images. Concerning the global information description of 3D models, a light field descriptor (LFD) is proposed in [4]. LFD is computed from 10 silhouettes obtained from the vertices of a dodecahedron over a hemisphere. This image set shows the 3D model from different views, and tries to describe the spatial structure information from different views. In LFD, Zernike moments and Fourier descriptors are employed to describe each image. Another view-based method, named the elevation descriptor (ED) [20], has been proposed recently. Six elevations are obtained from six different views to describe 3D models. 3D model comparison is based on the comparison of these six elevations. ED is invariant to translation, rotation, and scaling of 3D models. A spatial structure circular descriptor (SSCD) [5] is proposed to compare two 3D models. In SSCD, the 3D model is projected to a plane, and the comparison between two 3D models is based on the matching between the two groups of SSCD images.

View-based 3D model retrieval algorithms compare 3D models using view sets. As images representing a 3D model are captured from different views surrounding the model, 3D model retrieval should consider the spatial information of images.

In this paper, we propose a view-based 3D model retrieval algorithm based on probabilistic graph model. In the proposed algorithm, a two-level comparison scheme—the view level and the model level—for view based 3D model retrieval is presented. Several circle camera arrays are employed to capture views. Addressing the 3D spatial relationship, each individual view set is modeled as a first order Markov Chain. The task of 3D model retrieval is defined as a probabilistic analysis procedure, and the

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comparison between two models is to compute the conditional probability of one model given the other. The purpose to search models is to find the maximal a posteriori probability of the models in the database given the query. Under this probabilistic framework, we present a solution to estimate the conditional probabilities. In the view comparison procedure, the matching between each two view sets is analyzed. In the model level, all comparisons between two view sets are taken into account to generate the final matching result. The proposed algorithm can represent the relationship among different parts of the 3D model accurately and decrease the influence of 3D model rotation and transformation.

The remainder of this paper is organized as follows. Section 2 illustrates the 3D model retrieval algorithm using probabilistic graph model. Experiments and comparison with other methods are presented in Section 3. Conclusions and future works are given in Section 4.

## 2. 3D model retrieval using probabilistic graph model

The task of 3D model retrieval is to find matching/similar models from database. Given a query model  $\mathcal{Q}$  and a 3D model database  $\mathcal{DB}$ , the key for 3D model retrieval is to measure the similarities between the query and models in the database efficiently and effectively.

Following this proposed 3D model retrieval algorithm using probabilistic graph model is presented in details. First the representative views selection approach is given, and then the probabilistic graph based method is proposed.

### 2.1. Selection of 2D views

To capture a set of views for a 3D model, we set circle camera arrays to capture views. First we need to estimate the vertical direction of the 3D model. To estimate the vertical direction (the z axis in the three dimensional coordinate system), PCA [24] is employed to find the principal axis. There are two possible positive directions of the vertical direction. We randomly select one direction as the positive vertical axis from the two candidates. When the vertical direction is determined, five circle camera arrays are set to capture views of 3D models. The circle selection for camera array setting is shown in Fig. 1. As shown in Fig. 1, there are totally one horizontal circle camera array and four vertical circle camera arrays for one 3D model. In each circle, each two adjacent cameras have the same interval.

Using the above camera setting, 3D models are put in the center of the sphere, and each model contains five groups of 2D views (each view set is captured by a circle camera array).

When all groups of 2D views are captured, comparison of 3D models contains two stages: comparison at the view set level and comparison at the model level.

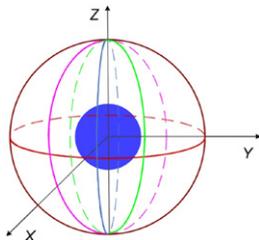


Fig. 1. Illustration of circle camera arrays setting.

### 2.2. Comparison in the view set level

In this part, we introduce the details of comparison in the view set level.

Let  $\mathcal{Q}$  be the query model,  $\Psi^{\mathcal{Q}} = [\psi_1^{\mathcal{Q}}, \psi_2^{\mathcal{Q}}, \dots, \psi_{\kappa}^{\mathcal{Q}}]$  be a view set of  $\mathcal{Q}$ , where  $\psi_i^{\mathcal{Q}}$  is  $i$  th view in the view set, and this view set contains  $\kappa$  views. Let  $\mathcal{DB}$  be the 3D model database, containing  $n$  models.  $\mathcal{R}$  represents a 3D model in  $\mathcal{DB}$ . Given a 3D model  $\mathcal{R} \in \mathcal{DB}$ ,  $\Psi^{\mathcal{R}} = [\psi_1^{\mathcal{R}}, \psi_2^{\mathcal{R}}, \dots, \psi_{\kappa}^{\mathcal{R}}]$  is the view set of model  $\mathcal{R}$ . This view set contains  $\kappa$  views too.

In this procedure, the task is to find the relationship between the two groups of 2D circle views. As a good matching result, one model should reflect much information of the query model. In other words, when users could imagine the 3D model information in the database from the query, the model is a good retrieval result. Due to this analysis, the relationship between the query and one model could be described as a posterior probability  $P(\mathcal{R}|\mathcal{Q})$ . This expression indicates the probability of a 3D model  $\mathcal{R}$  given the query  $\mathcal{Q}$ . Under these two view sets, our objective of 3D model retrieval is to find the maximal a posterior (MAP) in the 3D database, and this can be illustrated using the following equation:

$$r = \arg \max_{\mathcal{R} \in \mathcal{DB}} P(\mathcal{R}|\mathcal{Q}),$$

As the views describing one 3D model contains spatial information, there are strong relationship between each two adjacent views in one view set. When comparing two view sets of 3D models  $\mathcal{R}$  and  $\mathcal{Q}$ ,  $P(\mathcal{R}|\mathcal{Q})$  can be calculated as Eq. (1).

$$P(\mathcal{R}|\mathcal{Q}) = P(\Psi^{\mathcal{R}}|\Psi^{\mathcal{Q}}) = P(\psi_1^{\mathcal{R}}, \psi_2^{\mathcal{R}}, \dots, \psi_{\kappa}^{\mathcal{R}} | \psi_1^{\mathcal{Q}}, \psi_2^{\mathcal{Q}}, \dots, \psi_{\kappa}^{\mathcal{Q}}) \propto P(\psi_1^{\mathcal{Q}}, \psi_2^{\mathcal{Q}}, \dots, \psi_{\kappa}^{\mathcal{Q}} | \psi_1^{\mathcal{R}}, \psi_2^{\mathcal{R}}, \dots, \psi_{\kappa}^{\mathcal{R}}) P(\psi_1^{\mathcal{R}}, \psi_2^{\mathcal{R}}, \dots, \psi_{\kappa}^{\mathcal{R}}) \quad (1)$$

To simplify the computation of Eq. (1), we approximate it by assuming that:

- $P(\psi_i^{\mathcal{Q}}|\psi_i^{\mathcal{R}})$ ,  $i=1,2,\dots,m$  are independent of each other;
- $P(\psi_1^{\mathcal{R}}, \dots, \psi_{\kappa}^{\mathcal{R}})$  can be modeled as a first-order Markov chain, and  $P(\psi_i^{\mathcal{R}}|\psi_{i-1}^{\mathcal{R}}, \psi_{i-2}^{\mathcal{R}}, \dots, \psi_1^{\mathcal{R}}) = P(\psi_i^{\mathcal{R}}|\psi_{i-1}^{\mathcal{R}})$ . As the views are captured using a circle camera array, the order of views is known as pre-knowledge.

The above assumptions can make Eq. (1) be rewritten as

$$P(\mathcal{R}|\mathcal{Q}) \propto P(\psi_1^{\mathcal{Q}}|\psi_1^{\mathcal{R}}) P(\psi_1^{\mathcal{R}}) \times \prod_{i=2}^{\kappa} P(\psi_i^{\mathcal{Q}}|\psi_i^{\mathcal{R}}) P(\psi_i^{\mathcal{R}}|\psi_{i-1}^{\mathcal{R}}), \quad (2)$$

and this is a form of hidden Markov models (HMM). To calculate Eq. (2), two components are considered: the probability of direct view matching (PDVM)  $P(\psi_i^{\mathcal{Q}}|\psi_i^{\mathcal{R}})$ , and the probability of view transition (PVT)  $P(\psi_i^{\mathcal{R}}|\psi_{i-1}^{\mathcal{R}})$ . PDVM illustrates the probability of a single query view  $\psi_i^{\mathcal{Q}}$  given a single model view  $\psi_i^{\mathcal{R}}$ , and PVT indicates the probability of a 3D model view  $\psi_i^{\mathcal{R}}$  given  $\psi_{i-1}^{\mathcal{R}}$ . By specifying PDVM and PVT, we can derive a probabilistic framework for 3D model retrieval. Estimation of PDVM and PVT is presented as follows.

#### 2.2.1. PDVM estimation

To estimate PDVM, the 49 coefficients of Zernike moment are employed as the view feature. Zernike moment is robust to image translation, scaling, and rotation. Zernike moment has been applied in many works of 3D model analysis, and it has been approved the effectiveness for 2D views description.

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