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3D model retrieval and classification by semi-supervised learning with content-based similarity

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ABSTRACT

The rapid development of 3D digital technology has led to an increasing volume of 3D model data. In addressing the management of such large scale data, effective content-based 3D model retrieval and recognition methods are highly desirable. In 3D model retrieval and recognition tasks, the distance measure between two 3D models plays an important role. In this paper, we propose a novel 3D model retrieval and recognition method that employs both a distance histogram and 3D moment invariants as features that are invariant to 3D object scaling, translation, and rotation. Disjoint information is used to measure the distance between the feature histograms, and the Euclidean distance is applied in calculating the distance between two moment features. These measures are then combined as the 3D model distance. Using this distance measure, the relationships between all 3D models in the dataset are formulated as a graph structure. A semi-supervised learning process is then conducted to estimate the relevance among the 3D models, and this is employed for 3D model retrieval and classification. To evaluate the effectiveness of the proposed method, we conduct experiments on two datasets. Experimental results and a comparison with state-of-the-art methods demonstrate that the proposed method achieves improved performance for 3D model retrieval and recognition tasks.

1. Introduction

Rapid advances in computing techniques and 3D technologies [4,11,23,32] have led to the widespread application of 3D models [6] in many areas, including 3D graphics technologies, computer aided design, 3D movies, and other 3D related entertainment [5,8]. Because 3D models play an increasingly important role in many applications, the number of 3D models has increased significantly. Nevertheless, creating effective and efficient search methods for large scale 3D model database is an urgent and challenging problem. Hence, researchers from many well-known institutions and universities [12,13,16,30,42] are focusing on the task 3D model retrieval and recognition. Combined with this extensive research effort [17], many public datasets [42] have been released in recent years.

In 3D model retrieval and recognition, the key issue is to measure the distance between two 3D models. Many descriptors and distance measures have been proposed. Low level features, such as geometric moments [39], surface distribution/geometry [21,36], and volumetric descriptors [21,36] can be employed for 3D model description. It should be noted that most of the existing low-level features are dependent on statistical methods. The major limitation of using such low level features is

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the difficulty in then determining global information about the 3D models. Other methods [41] extract high level structure-based information as 3D model descriptors. View-based methods [14,27,44] have been developed, such as the Light Field Descriptor (LFD) [7], Elevation Descriptor (ED) [41], and Compact Multi-View Descriptor (CMVD) [10]. In these methods, each 3D model is represented as a group of views. For general multimedia information retrieval and classification tasks, existing distance measures, such as the Euclidean, Minkowski, and Mahalanobis distances, can be employed. Some typical distance measures employed in existing methods are summarized below.

(1) Hausdorff distance [3]. Also called the Pompeiu–Hausdorff distance, this measures the distance between two subsets in a metric space

$$D_{haus}(\mathcal{M}_1,\mathcal{M}_2) = \max\left\{\max_{m'\in\mathcal{M}_1}\left\{\min_{m''\in\mathcal{M}_2} d(m',m'')\right\},\ \max_{m'\in\mathcal{M}_2}\left\{\min_{v''\in\mathcal{M}_1} d(m',m'')\right\}\right\}. \quad (1)$$

(2) Minimal distance. This calculates the minimal distance between two groups of features and is defined as

$$D_{min}(\mathcal{M}_1,\mathcal{M}_2) = \min_{m'\in\mathcal{M}_1, m'\in\mathcal{M}_2} d(m',m'). \quad (2)$$

(3) Sum–min distance [10]. The sum–min distance calculates the sum of the minimal distance for each component. It is defined as

$$D_{sum\_min}(\mathcal{M}_1,\mathcal{M}_2) = \frac{1}{|\mathcal{M}_1|}\sum_{m'\in\mathcal{M}_1}\min_{m'\in\mathcal{M}_2} d(m',m'). \quad (3)$$

(4) Bipartite graph matching. If a 3D model can be described as a group of features, such as multiple views, it can be formulated as a bipartite graph structure. Optimal matching of this bipartite graph is then conducted to measure the distance between two 3D models.

Although there are many existing measures of the distance between 3D models, these are mainly based on one-to-one matchings that cannot reveal the underlying relationships among the 3D models. Therefore, effective distance measures are still urgently required. Another issue involves estimating the relationships among all 3D models in the dataset. To address these problems in 3D model retrieval and recognition tasks, we propose a 3D model distance measure that uses disjoint information. In this method, feature histograms are employed as the 3D model descriptor, and the disjoint information between two feature histograms is calculated to measure the distance between the two 3D models. To further enhance the distance measure, 3D moment invariants are employed as a second feature and the Euclidean distance between the moment features is combined with the disjoint information-based distance. Using this combined 3D model distance measure, the relationships among all 3D models in the dataset can be formulated as a graph structure. A semi-supervised learning process is then performed to estimate the relevance between 3D models, which is useful in 3D model retrieval and classification. Fig. 1 illustrates the system architecture of the proposed method. To evaluate the performance of the proposed method, experiments were conducted on two public 3D model datasets, the National Taiwan University 3D Model database (NTU) [7] and the Princeton Shape Benchmark (PSB) [42]. Experimental results and a comparison with state-of-the-art methods demonstrate the effectiveness of the proposed method.

The rest of this paper is organized as follows. Section 2 briefly reviews related work in 3D model retrieval and recognition. Section 3 introduces the proposed 3D model retrieval and recognition method. Experiments validating the method are presented in Section 4, and we conclude the paper in Section 5.

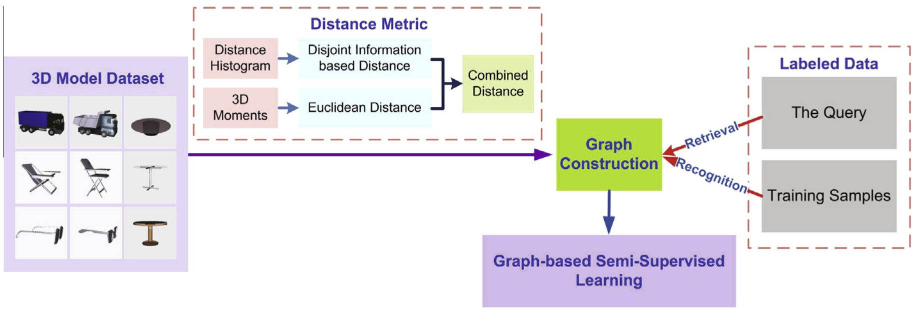

Fig. 1. Schematic illustration of the proposed 3D model retrieval and recognition method.