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Invariant feature extraction for 3D model retrieval: An adaptive approach using Euclidean and topological metrics

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ABSTRACT

With the fast development of 3D model construction and widespread popularity of 3D graphic engines, more applications employ 3D geometric models to provide an interactive environment. As the number of 3D models increases, some 3D model retrieval systems have been proposed for indexing and matching these models. An important issue in a retrieval system is feature extraction. An efficient and invariant feature is a global shape distribution that collects some geometric properties of a model. The D2 shape descriptor by Osada et al. is a one-dimensional histogram of Euclidean distances between two random points. Although the D2 is effective for some cases, it changes when the model deforms. We propose two shape descriptors in this paper: GD, which is the topological metric, and ASF, which combines both Euclidean and topological metrics. The topological metric is an invariant deformation factor. The two features are also robust against common geometric processing, including scaling, rotation, resampling, compression, and remeshing. In experiments, we implement these methods and confirm their feasibility.

1. Introduction

Because CAD software provides a powerful tool to create object shapes, an increasing number of applications use 3D geometric models to promote an interactive environment with impressive graphics. As Internet bandwidth grows, people can also directly disseminate 3D models over networks. With the enormous increase in the number of 3D models, we need a repository or system to manage these models. An important mission for the system is building efficient indexing and matching for 3D models. Although we can use the traditional caption-based feature for indexing, which helps efficient searching in traditional databases, this approach cannot completely represent all possible semantics for all people because annotations added by humans depend on personal characteristics, including culture, language, and age. Content-based retrieval has recently become mainstream, especially in audio [1], images [2–5], and video [6]. For a 3D model retrieval system, we need some 3D model features for indexing and matching. These content-based features are extracted directly from 3D models, and these features can represent the intrinsic characteristics of the models. Finding an appropriate feature representation of 3D models thus becomes a key point in developing a content-based retrieval system.

Researchers have recently devoted studies to 3D model retrieval-related technologies. On the basis of the query methods, we may roughly divide these technologies into three categories, including query by text, query by sketch, and query by example. The text-based query, as in full-text retrieval, adopts the structured query language (SQL) to make the feature description; however, everyone depicts a model differently for his or her perception, and some high-level semantics of the

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model are difficult to illustrate by text. The sketch-based query draws some 2D silhouettes of a required model and searches for all models with similar silhouettes. However, some models do not have impressive silhouettes, and people do not know how to draw them. Moreover, there are no notable differences among the silhouettes of many models, and the silhouettes cannot represent enough model features. The last strategy is to search for similar models using an example model. The system automatically compares a given model to all in the database and returns similar 3D models. To save searching time, the system often indexes these models by some descriptors.

In general, an ideal 3D model descriptor should satisfy the following criteria:

- High accuracy: In general, the accuracy rate from high-level semantics is often anticipated to be inferior due to a lack of intelligent human cognition. It is thus essential to obtain a high accuracy rate from aspects of intrinsic properties, including geometry and topology.
- High efficiency: As the number of 3D models increases, retrieval time is computation-intensive. Reducing retrieval feedback latency is an essential consideration. The model descriptor computation cannot take much time, and the indexing technology must be efficient.
- Feature invariance: In many CG-related applications, 3D models are often simplified or remeshed for fast rendering purposes. Models may also be transformed by translation, rotation, scaling, or reflection operations. After these processes, the intrinsic content of a model does still not change; a representative descriptor or feature should therefore maintain invariance.
- General representation: Many modelling methods have been applied to build 3D objects in commercial modelling tools, providing many representations for 3D models. The common representations include meshes, curved surfaces, and CSG. However, a feature descriptor of a 3D model must be independent of representations.
- Adaptive features: When the descriptions of some models are ambiguous, people want to obtain feedback from the system and make comments on it. It should thus be possible to penetrate some adjustable parameters to provide successive queries.

In this paper, we develop a novel 3D shape descriptor and provide efficient retrieval via a query by example interface. The key contribution of this paper is that the proposed descriptor is composed of both geometric and topological characteristics. Thus, the shape descriptor is invariant to possible modifications, including deformation, scaling, translation, resampling, and geometry compression. The last sections are organized as follows. In Section 2, we review previous work on content-based 3D retrieval. Section 3 discusses various metrics for shape descriptors and proposes two novel metrics with deformation invariance. Section 4 shows the experimental results, and Section 5 is the conclusion.

2. Related work

Researchers have recently proposed much work on content-based 3D shape retrieval [7–26]. Tangelder et al. [7] and Yang et al. [8] provided some surveys for these methods. The efficient features from 3D shapes are important for a 3D model retrieval system. Zhang and Chen [13] extracted features such as volume, moments, and Fourier coefficients from the mesh representation. As when using a quadtree to represent a 2D image, principal component analysis is commonly used for registration before matching the feature. Wang et al. [14] proposed the octree structure to represent 3D models after PCA standardization. According to the 3D model shape distribution, each node is recursively subdivided into eight nodes until conforming to meet a human's visual accuracy. When comparing corresponding nodes, i.e., those with the same depth and position, in two octrees, we may measure the similarity of two 3D models. Because each node in an octree represents a different sub-model size, the similarity measure is a weighted sum of these nodes' relation.

The 2D silhouettes of a 3D model are important characteristics for human vision. However, the contour line may change due to different viewing angles. Okada et al. [15] defined the main three axes using PCA and obtained the 2D silhouette images projected along the three main axes. Based on these three-projected images, the central moment is calculated from a 2D silhouette with respect to a central point and treated as a feature. Because no single 3D model has obvious and stable silhouettes, the outline also depends on the user's imagination. This strategy presents difficulty for obtaining a satisfying result. Some research adopts the PCA approach for pose normalization. Funkhouser et al. [16], however, indicated that PCA is not always feasible, for example, when two 3D models are in the same category, but their axes have different metrics.

In [17], the vertex distribution was used to represent 3D model characteristics. These studies used the vertex distribution shape histogram to analyse the similarity of 3D molecular surfaces. The histogram is defined on concentric shells and sectors around the centroid of a model. The drawback of the method is that the distribution of vertices differs after resampling.

In [17,19], a matching approach based on topology similarity was proposed. The main idea is to partition a 3D model into slices, construct the Reeb graph according to links between adjacent slices, and finally compare graph similarities. This strategy is suitable for matching deformable models, but the computation time is too long for practical applications.

The histogram-based feature expression may use multi-dimensional indexing, including the k-d or MX tree, which is helpful for efficiently searching a large database. In content-based image retrieval, the extracted feature is thus often represented in the form of a multi-dimensional feature vector. Osada et al. [20,21] expressed the signature of an object as a shape distribution sampled from a shape function measuring an object's global geometric properties. This approach reduced the shape matching problem to comparing probability distributions, which is simpler than traditional shape matching methods that require pose registration, feature correspondence, or model fitting. The experimental results show that the