Pattern Recognition 43 (2010) 1142–1151

Contents lists available at ScienceDirect

Pattern Recognition

journal homepage: www.elsevier.com/locate/pr

3D model comparison using spatial structure circular descriptor

Yue Gao, Qionghai Dai*, Nai-Yao Zhang

Tsinghua National Laboratory for Information Science and Technology, Department of Automation, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 16 December 2008
Received in revised form 19 July 2009
Accepted 24 July 2009

Keywords:
3D model
Comparison
Retrieval
Spatial structure circular descriptor

ABSTRACT

This paper proposes a 3D model comparison algorithm based on a 3D model descriptor: spatial structure circular descriptor (SSCD). The spatial structure is important in content-based 3D model analysis. Within the SSCD, the spatial structure of a 3D model is described by 2D images, and the attribute values of each pixel represent 3D spatial information. Hence, SSCD can preserve the global spatial structure of 3D models, and is invariant to rotation and scaling. In addition, by using 2D images to describe the spatial information of 3D models, all spatial information of the 3D models can be represented by SSCD without redundancy. Thus, SSCD can be applied to many scenarios which utilize spatial information. In this paper, an SSCD-based 3D model comparison algorithm is presented. The proposed algorithm has been tested on 3D model retrieval experiments. Experimental results demonstrate the effectiveness of the proposed algorithm.

1. Introduction

Due to the advances in multimedia applications, the amount of 3D models are rapidly increasing, and the development of 3D model analysis systems is becoming increasingly essential. The 3D models illustrate complex spatial information, and they have been widely used in CAD, virtual reality, medicine, and entertainment.

Recently, many literatures [2,3,10,11,16,17,21,24–26,31] focus on model-based 3D object retrieval, such as 3D face model retrieval. The descriptor extraction method for 3D models [4] is an important issue for content-based 3D model analysis systems such as indexing and searching.

In the 3D model retrieval task, a good 3D descriptor should be effective for 3D structure description. How to describe the spatial structure of 3D models is another related problem. Generally, there are three types of methods for description: low-level feature-based methods, high-level structure-based methods, and view-based methods.

To address the spatial structure representation and expression ability of 3D model descriptor, a 3D model descriptor is presented in this paper. First a spatial structure circular descriptor (SSCD) is proposed. Then an SSCD-based 3D model comparison algorithm is provided. SSCD can preserve the global spatial structure of 3D models, and it is invariant to rotation and scaling. All spatial information of 3D model can be represented by an SSCD which includes several SSCD images. Each SSCD image uses a circular image to describe the surface (spatial) information of a 3D model. Each spatial part of a 3D model is represented by one part of the SSCD individually, and no interference among components of 3D models exists. The SSCD based 3D model comparison algorithm employs the histogram information to compare SSCDs, and bipartite graph matching method is used to find the minimal distance between two SSCDs.

This paper is organized as follows. Related works are given in Section 2. We introduce SSCD in Section 3. The SSCD-based 3D model comparison algorithm is given in Section 4. In Section 5, experiments on 3D model retrieval are provided to justify the effectiveness of the proposed algorithm. Section 6 concludes this paper.

2. Related works

The 3D model retrieval algorithms can be classified into three categories [27]: low-level feature-based methods, high-level structure-based methods, and view-based methods.

Low-level feature descriptors employ the geometric moment [22], surface distribution [19], volumetric descriptor [29], and surface geometry [8,9,20,23] to describe 3D models. Many low-level features are based on statistical methods, and 3D model retrieval is based on the low-level feature comparison.

The major difference between 2D images and 3D models is the spatial structure information. Low-level features have limitation on the global information representation of 3D models.

High-level structure-based methods [27] describe the relationship among different parts of the 3D model. View-based methods [5] represent 3D models using a number of images, and 3D models are described by a set of 2D images. Both of the high-level

* Corresponding author.
E-mail address: qionghaidai@tsinghua.edu.cn (Q. Dai).

0031-3203/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.patcog.2009.07.012

structure based methods and the view-based methods reflect the spatial structure of 3D models, and take the global information of 3D models into consideration. In the content-based 3D model retrieval task, the global spatial structure information of 3D models plays a more important role on determining the properties of 3D models compared with low-level features.

Concerning the global information description of 3D models, a light field descriptor (LFD) is proposed in [5]. LFD is computed from 10 silhouettes obtained from the vertices of a dodecahedron over a hemisphere, which is based on the image-based rendering method "light field" [13]. This image set shows the 3D model from different views, and describes the spatial structure information using these views. In LFD, Zernike moments and Fourier descriptors are employed to describe each image. The application of LFD in the analysis of the original 3D model global spatial structure is limited by the immaturity of existing 3D model reconstruction methods. LFDs may overlap each other, and generate the shape representation variance. Different views may have interference with each other. Furthermore, binary images are employed in LFD, where the spatial information is lost.

A global spatial information descriptor, elevation descriptor (ED) has been proposed in [27] recently. ED represents 3D models by the spatial information from six directions. It is invariant to translation, rotation, and scaling of 3D models. However, different elevation descriptors may overlap each other, and this limits its ability for global spatial structure representation. Another problem is that, if there are some cavities on the 3D model, ED cannot describe the inner structure of 3D model.

An extension ray-based descriptor (ERD) [30] employs concentric spheres to extract the surface information of 3D model. Each sampling surface point provides the nearest sphere surface with a corresponding value, and the descriptor is the vector of points in the surfaces of these concentric spheres. This method can describe the inside surface of 3D models. Concerning the spatial structure of a 3D model, the space between two subsurfaces may be parts of the 3D model, or just cavity. This information determines the exact spatial position of 3D models. The extension ray-based method can show the positions of surface, but it cannot discriminate the inner and the outer parts of 3D models. Extended Gaussian image (EGI) [7] employs the distribution of polygons normals to describe 3D model, where the 3D model is formed by these polygons. EGI maps the 3D model to a Gaussian sphere, and the comparisons of two EGIs are based on the comparison between two normal vectors.

3. The spatial structure circular descriptor for 3D models

In this section, the spatial structure circular descriptor for 3D models is presented in details.

3.1. The framework

Generally, content-based 3D model retrieval needs the representation of the global structure of 3D models. There are many existing 3D model retrieval algorithms [5,27], while there are still some limitations to represent the global structure as mentioned in Sections 1 and 2. How to describe the spatial structure information of 3D models in an intuitive and effective way is an important problem for 3D model analysis.

The view-based descriptors try to employ a set of 2D images to represent 3D models. These images cannot reflect the spatial structure well, and information redundancy does exist in the image set.

Concerning the task of using a 2D image to representing the spatial structure of a 3D model, the expected 3D model descriptor should have following properties. It represents the global spatial structure information well, and it is invariant to little detail/geometry changes of 3D models. Additionally, it is robust to rotation and scaling.

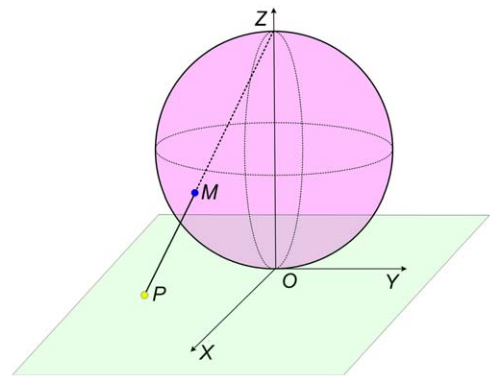

Fig. 1. The spherical grade projection. M is a point on the surface of the sphere, and P is the corresponding projection point on the XOY plane.

We are inspired by the spherical grade projection (SGP). Using SGP, the surface of a sphere can be projected on a plane. The procedure of SGP is as follows. Given a sphere, assuming it is transparent, light emits from the north polar and spreads along a straight line. Given a point M on the surface of the sphere, the light passes the point, and this light has a crossing point P on the projection plane (see Fig. 1 for illustration). P is the SGP point of M on the projection plane.

Using this method, any point on the sphere surface (except the north polar) can be projected on the XOY plane. The closer the point to the north polar, the further the projection away from the origin on the plane. The projection of the north polar is infinite. The whole sphere can be represented by the projection circular region. SGP is conformal. Though the sizes of each part on the surface of the sphere may change, the global structure is preserved in the projection image. SGP projects circulares on the surface of the sphere into circles on the XOY plane, except the circles passing through the north polar. The projections of the circles passing through the north polar are straight lines on the XOY plane. SGP does not preserve sizes, e.g. the parts near the south polar look tiny, while the shape does not change, even the links do. There is a limitation of SGP: the projection is an infinite circle region, which makes it difficult to use.

Inspired by SGP, an improved 3D model descriptor, SSCD, is presented in this paper. In the SSCD generating framework, first a minimal bounding sphere of the 3D model is computed. All points on the 3D model surface are projected to the bounding sphere, and each point in the sphere is given one or more attribute values, representing the surface spatial information. To facilitate the description of global structure, the bounding sphere is projected to a plane, where a projection method is provided to keep the projection region finite. The projection drawing is a circular region, and the project method is conformal. It can preserve the spatial structure of the original 3D model.

The vertical direction has influence on the position of the projection plane. Though the global spatial structure is the same under different projection planes, there are large differences with the description of the global spatial structure. Thus, the first step is to estimate the vertical direction. To estimate the vertical direction (the z-axis in the 3D coordinate system), PCA [30] 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. The 3D model comparison method using SSCD can eliminate the influence of 3D model rotation.