3D Part based Structural Description Extracting and Modeling

Weiwei Xing, and Baozong Yuan

Abstract—**This paper presents part based structural description of 3D objects, which combines the geometric features of individual parts with topological connections among them. Superquadric-based geons are employed to be the primitive part representation models, which are compact and powerful in shape distinction. The structural description computing framework and the modeling system are developed, experiments are carried out and some results are demonstrated. The 3D model database is built on the modeling system, which lays a good foundation for further study on 3D object analysis and recognition.**

Index Terms—**Part based, structural description, 3D object, modeling**

I. Introduction

THREE dimensional object reconstruction, analysis and recognition are very important in many application and research fields, such as robotics, virtual reality and computer vision, where the powerful 3D object description is very crucial. Part based representation has been used widely in computer vision [1-3] as it is viewpoint independent, insensitive to local variations and supported by extensive psychological evidence.

In this paper, superquadric-based geon models are first implemented for representing the parts involved in 3D objects, which enables a more compact 3D object representation. Then, the geometric features of individual parts and topological connections among them are described and extracted. The structural description computing framework is developed, which shows the processing steps from 3D object data to the structural description, meanwhile some experiments on structural features extraction are conducted for evaluating the performance of the presented method. Finally, a modeling system is implemented for building 3D model database in order to lay a foundation for further study on 3D object analysis and recognition.

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II. 3D Part representation: superquadric-based geons

As the compact and powerful representation for 3D parts, superquadric-based geons (SBGs) are employed in this paper, which combine superquadric quantitative information and geons' qualitative attributes.

A. Superquadric model

Superquadrics as a family of parametric shapes can describe a wide variety of relatively complex and realistic 3D primitive shapes effectively with compact parameters [4]. A basic superquadric surface may be defined by an implicit equation:

$$f(x,y,z)=((\frac{x}{a_x})^{2/\varepsilon_2}+(\frac{y}{a_y})^{2/\varepsilon_2})^{\varepsilon_2/\varepsilon_1}+(\frac{z}{a_z})^{2/\varepsilon_1}-1=0 \quad (1)$$

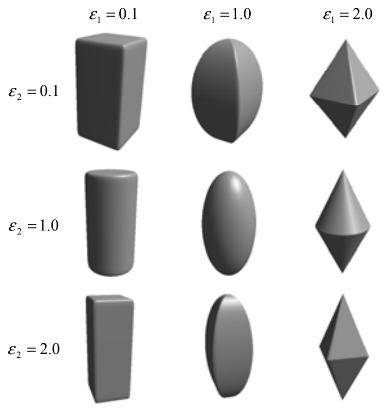

Fig. 1. Superquadric models with different shape parameters $\varepsilon_1, \varepsilon_2$ (Keeping constant size parameter a_x, a_y, a_z)

The modeling power of superquadrics can be augmented by applying various deformation operations, such as bending, tapering [4,5] to the basic superquadrics.

B. RBC and geons

Biederman's RBC (Recognition-By-Components) theory [3] provides a promising computational framework for object recognition and postulates a finite set of distinct volumetric shapes called "geons" as the basis for object representation. RBC theory maintains that the set of geons apparently have sufficient representational power to express humans' ability for basic visual recognition, the visual system readily decomposes the objects into such components and represents them in terms of their geons and the invariant relationships among them. Geons are classified according to four qualitative geometrical attributes: axis shape, cross-section edge shape, cross-section size sweeping function, and cross-section symmetry [6].

These attributes provide distinct shape characteristics

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useful for symbolic object recognition [7]. Psychological experimentation has provided supports for the descriptive power of geon-based description [8] and geon models have been proposed as a basis for numbers of object recognition systems [7,9].

C. *Superquadric-based geons*

As the information offered by geons is only qualitative [9], using geon-based description would not be very efficient in usual cases. In this paper, superquadrics as a unified quantitative parametric shape models are implemented to represent geons due to superquadric powerful modeling capability and extensive implementation in computer vision.

Superquadric-based geons introduce the quantitative description of superquadric models into the intrinsic qualitative information purely offered by geon-based representation, which greatly enhance the discriminative power of geons. In this paper, the same selection of geons as [10] is used, which ignored the symmetry attribute in geons' features, i.e. a set of twelve geons modeled by globally deformable superquadrics according to three attributes, axis shape (straight or bent), cross-section edge shape (straight or curved) and cross-section size sweeping function (constant, increasing-and-decreasing, or tapered).

III. STRUCTURAL DESCRIPTION AND FEATURE EXTRACTION

The structural description of 3D objects based on SBGs is implemented at two levels, geometric level features representing the shape attributes of each object part and topological level features reflecting the global connections among these parts.

A. *Geometric features*

Superquadric parameters

A superquadric surface is defined by an implicit equation (1). At a first step toward fitting superquadric to 3D data, an inside-outside function is defined as follows:

$$F(x,y,z) = [f(x,y,z)+1]^{\varepsilon_1} \quad (2)$$

For a superquadric model in general position and orientation with linear tapering and bending deformations, the inside-outside function may be written as an implicit function (3) with 15 parameters.

$$F(X,Y,Z) = F(X,Y,Z;a_x,a_y,a_z,\varepsilon_1,\varepsilon_2,\varphi,\theta,\psi,p_x,p_y,p_z;K_x,K_y;K_b,\alpha) \quad (3)$$

Given the 3D data is a set of points (x_i,y_i,z_i), $i=1,2,\cdots,N$, which correspond to the description of 3D real object part. The goal of superquadric fitting is to change the 15 parameters to find the values for which most of the 3D points are close to the superquadric surface. The best fitting may be obtained by searching for the minimum of the energy of E:

$$E=\sum_{i=1}^{N}\sqrt{a_xa_ya_z}\left[1-F\left(x_i,y_i,z_i;a_x,a_y,a_z,\varepsilon_1,\varepsilon_2,\varphi,\theta,\psi,p_x,p_y,p_z;K_x,K_y;K_b,\alpha\right)\right]^2 \quad (4)$$

where a_x,a_y,a_z are defined for the superquadric size, $\varepsilon_1,\varepsilon_2$ characterize the shape, φ,θ,ψ are defined for the orientation and p_x,p_y,p_z for the position in space, K_x,K_y are defined for tapering deformation along Z axis and K_b,α for bending deformation.

Through the nonlinear minimization of (4), the superquadric parameters describing 3D part data are obtained [5].

Based on the superquadric parameters of 3D object parts, other shape features at geometric level can be defined and extracted.

Geon type FU_{geon}

It is the qualitative attribute of 3D object part. On the basis of the superquadric parameters obtained above, a set of discriminative features are first derived as a feature vector; then, the geon classification is implemented utilizing SVM-based multi-class classifier and the geon type of the object part is achieved.

3D spherical harmonic descriptor FU_{sph}

This is a 3D rotation invariant describing part shape. The FU_{sph} extraction of 3D part represented by superquadric is decomposed into three steps: first, sample regularly on superquadric surface along the longitudinal and latitudinal directions; then construct spherical function describing superquadric surface based on the obtained samples; finally, implement fast spherical harmonic transformation on the spherical function and obtain the 3D spherical harmonic descriptor.

Volume ratio FU_{Vratio}

The ratio of current part volume to the whole object volume reflects the part's spatial occupancy. Due to the clear equation of superquadric, it is simple to compute the part volume represented by superquadric [11].

Elongations FU_{elong}

This feature consists of two elements $FU_{elong1}=\frac{a_{max}}{a_{med}}$ and $FU_{elong2}=\frac{a_{med}}{a_{min}}$, where a_{max},a_{med},a_{min} are the maximal, medium and minimal superquadric size parameters of volumetric part along X,Y,Z axis (among a_x,a_y,a_z) respectively.

B. *Topological features*

Part connection number FU_{Pnum}

It is the number of parts connecting with the current part. In Fig.2, part P_1 connects with other parts P_2,P_3,P_4,P_5 and thus FU_{Pnum} of P_1 is 4.

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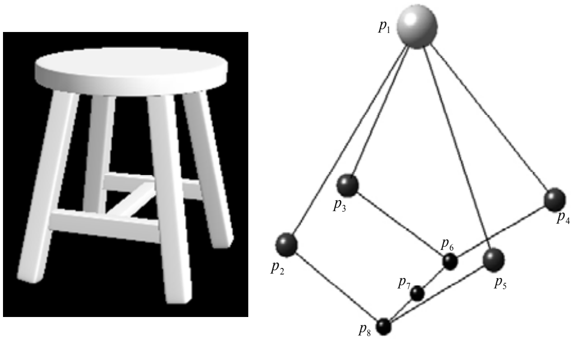

Fig. 2. Demonstration of part connection number feature

Connections $FB_{connect}$

This feature represents the connection relationship of one part with other parts of 3D object. $FB_{connect}$ is denoted by a connection relationship matrix, where the row number is the part label and the elements in this row are the part labels connecting with the current part, other elements are assigned -1. As for the model in Fig.3, its connections matrix is the following:

$$\begin{bmatrix} 2 & 4 & -1 & -1 & \cdots \\ 1 & 3 & -1 & -1 & \cdots \\ 2 & -1 & -1 & -1 & \cdots \\ 1 & -1 & -1 & -1 & \cdots \end{bmatrix}$$

Connection type $FB_{contype}$

It reflects the number of intersections between two parts, which corresponds to $FB_{connect}$. In Fig.3, its connection type matrix is

$$\begin{bmatrix} 1 & 2 & -1 & -1 & \cdots \\ 1 & 1 & -1 & -1 & \cdots \\ 1 & -1 & -1 & -1 & \cdots \\ 2 & -1 & -1 & -1 & \cdots \end{bmatrix}$$

where 1 denotes one connection and 2 for two connections.

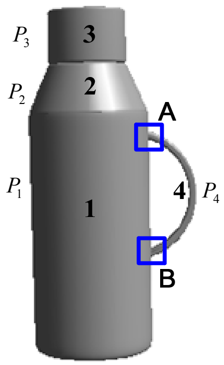

Fig. 3. The thermos model

C. *Structural description*

The structural description computing framework of 3D objects is demonstrated in Fig.4.

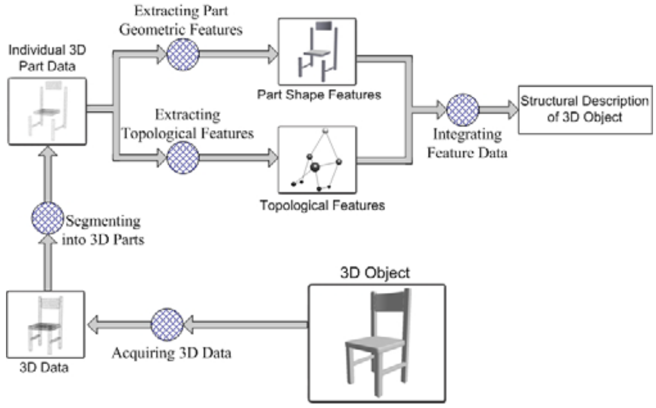

Fig. 4. 3D object structural description computing framework

The main processing steps are as follows:

1) Acquiring 3D data: The real-world 3D object surface data can be acquired by 3D data acquisition devices; however, due to the existing noises or part data loss, the preprocessing on the acquired original 3D data is implemented to fit the following computation.
2) Segmenting into 3D parts: The 3D parts of object constituents as well as connections among parts are obtained by segmentation.
3) Extracting part geometric features: First, 3D part data is fitted to get superquadric parameters and classified into some geon type FU_{geon}; then other geometric features of 3D spherical harmonic descriptor FU_{sph}, volume ratio FU_{Vratio} and elongations FU_{elong} are computed.
4) Extracting topological features: On the basis of segmentation, the global connection features among 3D parts are identified and symbolized, including part connection number FU_{Pnum}, connections $FB_{connect}$ and connection type $FB_{contype}$.
5) Integrating feature data: By combining the geometric features data and topological features, the structural description of 3D object are achieved for further recognition or analysis.

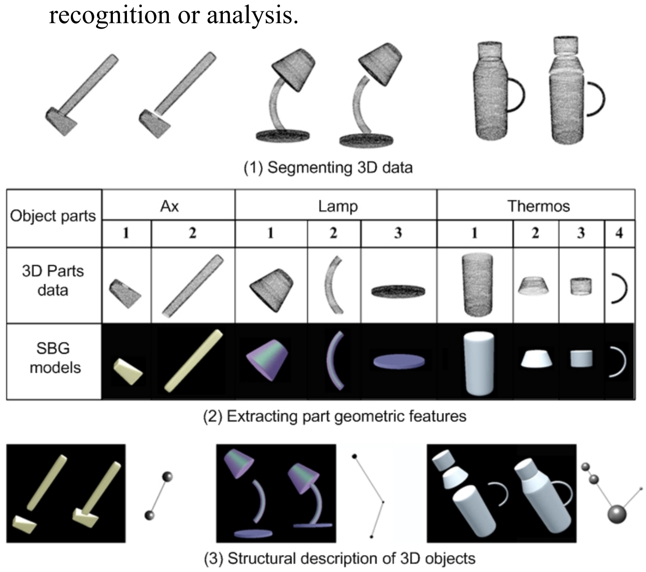

Fig. 5. Examples on extracting structural description of 3D objects

Based on the presented framework, experiments are

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carried out and some examples of extracting structural description for 3D objects are shown in Fig.5.

An application for extracting structural description of 3D object data is developed as shown in Fig.6, where taking a chair as an example. The application serves as a useful visual tool.

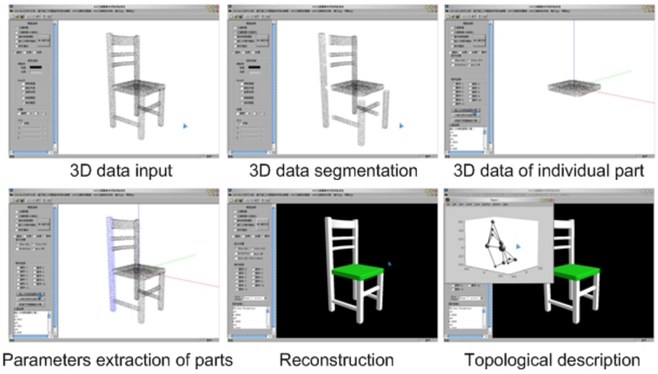

Fig. 6. Application for extracting structural description of 3D object data

IV. 3D OBJECT MODELING SYSTEM

A superquadric based visual object modeling system is developed, on which 3D models with different part number and different part shape can be constructed in real-time and interactive manner.

As for the modeling system, the left panel is for parameters control, and the right is the viewport of 3D model, which is shown in Fig.7. First, the individual part is created and edited by inputting and adjusting parameters; then all the created parts are assembled together by adjusting the position and orientation parameters; finally, the real-time operation and interactive control can be implemented in 3D viewport. Additionally, the existing models can be read and reedited for fast creating new 3D models, which improves the modeling efficiency greatly.

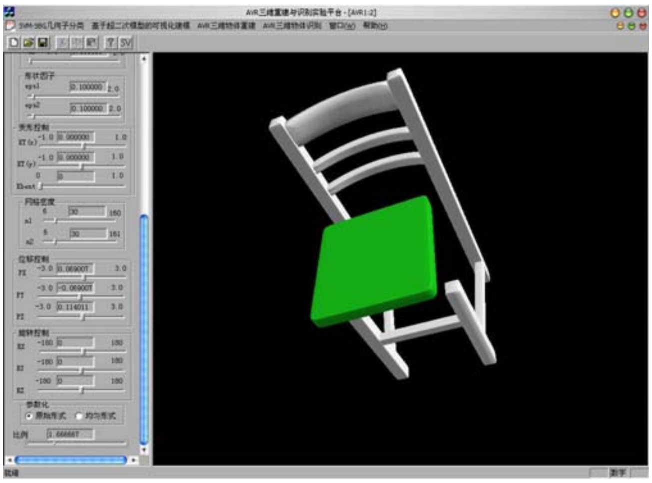

Fig. 7. Running interfaces of 3D object modeling system

Through the modeling system, a small-scale part based 3D model database is built for 3D object analysis and recognition. Fig.8 shows the building and organizing of the 3D model database.

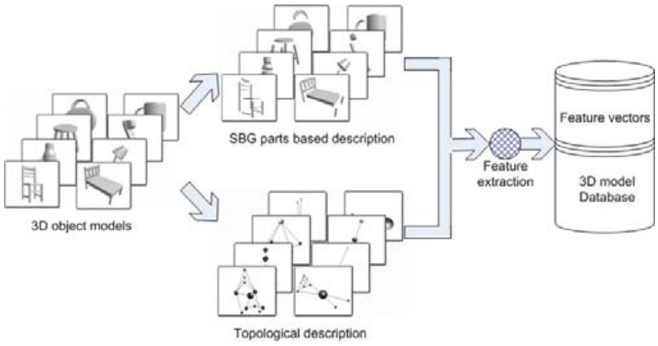

Fig. 8. Building and organizing of 3D model database

V. CONCLUSIONS

Superquadric-based geons provide a compact and powerful representation for 3D part shape distinction. The structural description is intuitive for 3D objects, and a framework for extracting structural description is implemented. Based on the description, a 3D object modeling system is developed, which is useful for building 3D model database.

The further study will focus on 3D object analysis and recognition, especially fast matching algorithms based on the compact structural description.

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