Automatic Object Modeling for 3D Virtual Environment

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Abstract

3D object modeling is an important issue in creation of virtual environment. This paper presents an automatic modeling approach for construction of curved object models. Our approach is based on the use of multiple images and superquadric modeling primitives. 3D model is generated from the contours on orthographic planes of images taken from known viewpoints, and represented with a set of superquadric primitives. The parameters of model are determined automatically by first utilizing a global fitting procedure where the silhouettes of the object are fitted to the parametric model, and then a local fitting strategy where some deformable parameters are adjusted to the object edges to refine the parametric model. Combining these fitting parameters, the geometric shape description of 3D objects can be obtained.

1. Introduction

3D object modeling is an important task in computer graphics, computer vision and many related application areas, such as modeling 3D object for pattern understanding and recognition; representing the real environment for robot programming and visual navigation; and constructing virtual environment for virtual reality system and applications. Most of current research and applications, however, to generate 3D object model depend on human operation [1-5]. Although many efforts have been carried out to realize an automatic 3D model generator, the problem that manual modeling costs much time and money is still remaining and it expects to develop a reliable technique that can automatically build accurate 3D object models for practical applications, such as virtual environment generation.

Currently, automatic construction of 3D object model by means of vision techniques has received increasing attention in computer graphics and virtual simulation domains. In the field of computer vision, for example, stereo technique is often used to build a partial object model [6]. Since the object model reconstructed by using stereo vision can only provide partial geometric information and it does not form a full 3D description of the object, some kinds fitting processing that integrates those partial models obtained from individual views are required to produce a complete 3D model. Other common practice in 3D object modeling is to use active sensing technique, such as laser rangefinder, to construct a complete 3D geometric representation by observing real objects from multiple views.

Volume intersection method is another kind of technique that generates 3D volume from 2D object silhouettes obtained in a sequence of images taken from known viewpoints. A 3D model of object is iteratively constructed by intersecting such volumes. Marttin and Aggerwel [7] developed an approach of 3D object modeling from orthographic views of 2D intensity images. The approach used rectangular parallelepiped segments as basic building blocks in the model. Kim et al also presented a rectangular parallelepiped based coding approach for 3D modeling [8]. They used silhouettes extracted from three orthographic views for model creation. The modeling technique by means of volume intersection has the advantage of being easy to implement, but it also has some limitations, such as it requires an accurate object-to-image space transform which is often hard to get, and an accurate estimation of object pose. If the pose parameters can not be obtained appropriately, the method can only produce an approximate object model. Actually, the models derived from volume intersection are simple polyhedral approximation to objects. While the volume intersection technique is easy to operate, it is difficult to apply for modeling complex 3D scenes, such as curved objects.

In recent years, as a superset of the traditional constructive solid geometry (CSG) modeling primitives, superquadrics have received significant attention for object modeling [10-14]. The main advantage of using superquadric primitives is that they can capture a large variety of shapes with a small number of parameters, and have nice mathematical properties, which lend themselves to efficient model recovery [11]. Superquadrics have been successfully used to approximate and model real 3D objects for various visual applications, such as range image interpretation, visual navigation and object recognition. We believe that superquadrics, with their simple and flexible shape description and more efficient recovery procedure, have tremendous potential for the modeling 3D objects in virtual environment simulation.

This paper presents an automatic modeling approach for construction of 3D curved object models. The extended superquadrics is adopted to represent models. Although many other parametric models can be used, such as the generalized cylinder or the symmetry-seeking model, the superquadrics are one of the best models that can represent various 3D real objects, such as cubes, cylinders, spheres, diamonds, and pyramids, etc. Furthermore, the extended sets of superquadrics can also be deformed to represent many irregular curved objects. In this approach, the models are generated from contours on orthographic planes of images taken from known viewpoints. The parameters of the models are determined automatically by an iterative procedure. Shape fitting for each image includes a global fitting strategy where the detected silhouettes of object are fitted to the parametric models and a local fitting where some deformable parameters are adjusted to the detected edges. Combining those fitting parameters, the geometric shape description of 3D objects can be obtained.

2. Superquadrics

The superquadrics consists of simple formula, but it can be used to describe a large family of complex 3D shape. Its power of representing complex shape is augmented by the applications of various deformations to its basic models. A generic superquadric surface can be defined as a closed surface in 3D space [9]:

$$r(h,w) = \begin{bmatrix} a_1 \cos^{e_1} h \cos^{e_2} w \\ a_2 \cos^{e_1} h \sin^{e_2} w \\ a_3 \sin^{e_1} h \end{bmatrix} \quad \begin{array}{c} -p/2 \le h \le p/2 \\ \\ -p \le w < p \end{array} \qquad (1)$$

There are five parameters in above equation, which define the shape and size of the superquadrics. e_1 and e_2 are the deformation parameters that control the shape of primitive, and parameters a_1, a_2 and a_3 defines the primitive size in x, y and z direction, respectively. By selecting different combination of these parameters, superquadric can model a wide variety of irregular shapes, and also many standard CG primitives as well

In practice, we often write it as an implicit representation:

$$\left(\left(\frac{x}{a_1}\right)^{\frac{2}{e_2}} + \left(\frac{y}{a_2}\right)^{\frac{2}{e_2}} \right)^{\frac{e_2}{e_1}} + \left(\frac{z}{a_3}\right)^{\frac{2}{e_1}} = 1 \qquad (2)$$

with an inside-outside function:

$$F(x,y,z) = \left((\frac{x}{a_1})^{\frac{2}{e_2}} + (\frac{y}{a_2})^{\frac{2}{e_2}} \right)^{\frac{e_2}{e_1}} + (\frac{z}{a_3})^{\frac{2}{e_1}}$$

Given any surface point (x, y, z), its position relative to the superquadric surface can be determined by the following rules:

$$F(x,y,z) = 1 \Leftrightarrow \text{point on the surface}$$

$$F(x,y,z) < 1 \Leftrightarrow \text{point inside the surface}$$

$$F(x,y,z) > 1 \Leftrightarrow \text{point outside the surface}$$

The closed surface defined by (1) or (2) is the standard superquadrics whose range of representing 3D shapes is limited in the symmetrical objects. However, the representation power of superquadrics can be augmented, to form an extended superquadric set by incorporating deformations, such as tapering, twisting and bending deformations into the basic formula, to model many irregular curved objects.

(1) Tapering deformation

Let *f(z)* is a linear function of z, such as $f_l(z) = l_z$, where l is the tapering parameter, then the tapering deformation in z direction can be described as:

$$\begin{cases} x' = g_1 x \\ y' = g_2 y \\ z' = z \end{cases} \tag{3}$$

where $g_1 = f_{l_1}(z)$, $g_2 = f_{l_2}(z)$, and $f_l(z) = l_z$.

(2) Twisting deformation

The twisting deformation of object can be formed by keeping the object constant in one direction, such as z, while allowing it deformation of rotation in other two directions.

$$\begin{cases} x' = x \cdot \cos g - y \sin g \\ y' = x \sin g + y \cos g \\ z' = z \end{cases} \tag{4}$$

where $g = f_l\,(z)$ such as $f_l\,(z) = lz$, where l is the twisting parameter.

(3) Bending deformation

Bending deformation is a kind of global deformation, which can be done by the following equations:

$$\begin{cases} x' = x \\ y' = (y - \frac{1}{l}) \cdot \cos g + \frac{1}{l} \\ z' = -(z - \frac{1}{l}) \cdot \sin g \end{cases} \tag{5}$$

By combining the basic model with those deformations, the sets of superquadrics are greatly extended to represent a wide variety of irregular shapes with a small number of parameters. Figure 1 shows the deformable surfaces with different parameters.

3. Generation of 3D model

The contours of images taken from known viewpoints are used for object modeling. Once the object contours are obtained by the preprocessing of edge detection and contour tracking, the contour points are globally fitted to the superquadric model. Then, a local fitting where the deformation parameters are adjusted to the local edges is performed. If the error of fitness meets a threshold requirement, the 3D model of the object is generated by combining all the parameters obtained from each image.

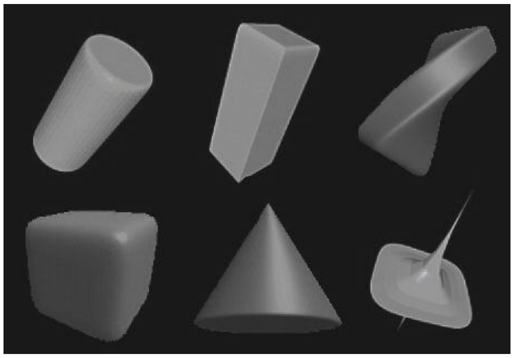

Figure 1 – Deformable superquadric surfaces with different parameters.

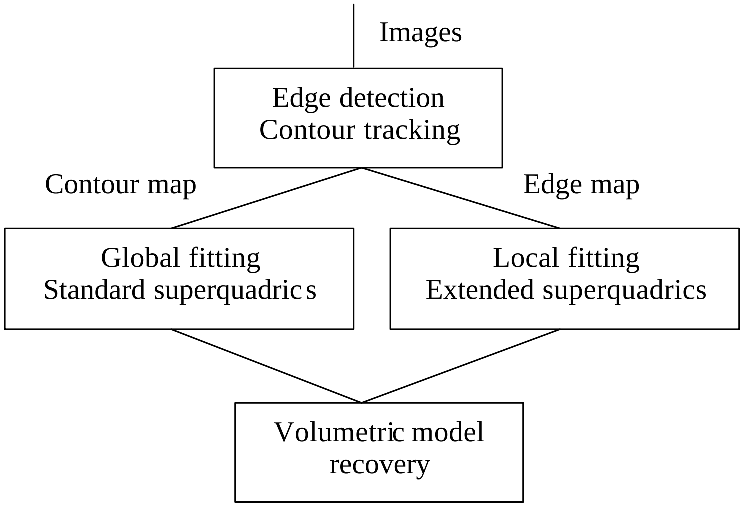

Figure 2 – Block diagram of the modeling approach

The fitting of contour points to the superquadric primitives is evaluated by a defined distance measure using the inside-outside function:

$$E = \frac{1}{N}\sum_{i=1}^{N}(\sqrt{a_x a_y a_z}(1 - f^{e_1}(x_i, y_i, z_i)))^2 \tag{6}$$

where (x_i, y_i, z_i) are the detected contours points, and (a_x, a_y, a_z) and e_1 are the deformable parameters defined in equation (1). Since the error function is nonlinear, the problem of fitting given contour points to superquadric model is a nonlinear estimation problem. In order to perform the nonlinear estimation procedure, Levenberg-Marquardt algorithm is used for solving the nonlinear least square minimization of the error function. As the first derivatives of the unknown parameters can be computed analytically, the procedure only requires a set of initial values. In our implementation, we align the origin of object-centered coordinate system to the center of gravity of all the N contour points. The site of initial fitting curve is the distance between the outermost contour points along each coordinate axis of the object-centered coordinate system.

If the fitting error of is small enough, for example, less than a pre-defined threshold, the model parameters are output as final fitting model. Otherwise, a local fitting procedure is performed to refine the results obtained from global fitting. Once the procedures of fitting images to the superquadric primitives are performed, the model of 3D object is generated by combining all the estimated parameters obtained.

4. Conclusion

This paper presented an automatic 3D modeling approach. The models, represented by the superquadric primitives, are created from the contours of images taken from known viewpoints. Both the standard superquadric sets and their extended subsets are used for handling irregular object surfaces. The modeling parameters are determined automatically using an integrated strategy of combining global fitting and local fitting. Final 3D object models are generated by combining all the parameters obtained from the model fitting. With this approach, 3D models of irregular objects can be constructed with litter user interaction. The approach has been successfully used to create a simple virtual environment. Improvements are underway to increase its capability of dealing with more complex scenes.

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