Three-Dimensional Geometric Modeling by Initial Model Modification

JUNTA DOI, YOHEI MIYAMOTO and SHINGO ANDO
Department of Computer Science
Chiba Institute of Technology
2-17-1, Tsudanuma, Narashino, 275-8588
JAPAN

TETSUO MIYAKE
Department of Production Systems Engineering
Toyohashi University of Technology
Hibarigaoka 1-1, Tempaku-cho, Toyohashi, 441-8580
JAPAN
miyake@keisys.tutpse.tut.ac.jp  http://www.tutpse.tut.ac.jp/

Abstract: - A new and versatile method of geometric modeling is proposed. Methods of geometric modeling for the object shape approximation proposed so far are “modeling-after-measurement,” but this proposal is “measurement-after-modeling.” A three-dimensional geometric model is transferred to another geometric model, by modifying the geometry of each mesh point, based on multi-directional images of the new object. The object is set on a precisely indexed turn table and rotated in a certain angle around the table axis. The initial model is also rotated in the same angle in the computer. Geometric coordinate values of each mesh point, which appears on the silhouette at the angle, are modified by using the silhouette image of the object or by measuring the mesh position. This method is not limited to the silhouette image but the position measurement is also applicable. Local modification is applicable to cope with the occluded difficulties inherent in the silhouette detection method. Transformations of a male model to another model of a female and a cylindrical model to a mannequin dummy model are demonstrated. Shape of the mesh and the vertex connectivity in the facet mesh of the initial model is conserved throughout the modification process and passes on the new geometric model. Desired meshing of the initial model transfers to the new. This is convenient to the use of numerical analyses such as FEM (Finite Element Method) and BEM (Boundary Element Method) in object approximate modeling and no further mesh generation required. Accuracy depends on the quality of the multi-directional imaging and/or position measurement. This modification only of the geometry and not of the topology will bring together the reuse of the initial model and the ease of modeling, starting from a simple geometric model with desired meshing.

Key-Words: - 3D geometric modeling, 3D model modification, Reuse of 3D model, Topology conserved model modification, Modeling of natural object, 3D machine vision.

1. Introduction
Geometric model generation for objects of, for instance, art, heritage, archaeology and medical applications, becomes important. Attempts to capture shape of objects and to reconstruct the geometric models have long history. Most of them, reported so far, are geometric modeling followed by shape measurements. Literatures are cited in many books and review articles [1-6]. They might be “Modeling-after-measurement.” As an example, multiple views with camera calibrated images are used for the purpose [6]. Techniques that operate under ambient illumination, requiring no dedicated light sources, are called passive method. Active techniques use the controlled projection light having point-wise, linear and/or various two-dimensional patterns. Most of the active methods measure the distance between the specific point on the object surface and a known position, the fixed point out side the object. Scanning is combined, for instance, by rotating the object or by moving the light source. So called triangulation and time-of-flight techniques are usually applied for this


distance measurement. Construction of the geometric models, such as the solid, surface and wire-frame models, of the object from the measured data is another important problem.

This paper deals with the geometric model transformation from an initially constructed model as the prototype to the object. We prepare an initial prototypal model, for instance, a solid model that is constructed using the computer graphics or computer aided design systems, is then transferred to another model to approximate the shape of the new object. Approximate modeling reported so far is the techniques that employ the shape measurement and model reconstruction based solely on the measured data.

On the other hand, our method is that the initially constructed geometric model is modified to approximate the shape of the object. In other words, topology of the new model succeeds to that of the initial, and geometry is modified by the object shape measurement. This might be “measurement-after-modeling” or “geometry-after-topology.” The new model is reconstructed by modifying the geometry of mesh points of the initial model. Fundamentally, the method is not limited to silhouette images but position measurement is also applicable to the mesh point modification.

The so called silhouette pyramid intersection method, that reconstruct a geometric model resulted from the intersection of multiple view pyramids, can directly approximate the three-dimensional shape of the object as shown in Fig. 1. An example of the lemon model shows linear (a distance from A to B in Fig. 2) and volumetric accuracies are about 0.5%. But the number and the shape of the facets of the resulted model vary according to measurements and are not uniquely decided even for the same object. An example of the result is shown in Fig. 2 [7]. In this paper the topology of the model, that is shape of the facet polygon and the vertex connectivity in the polygon, remains unchanged throughout the modeling procedure and passed on the new model. Number of the facet is as same as that of the initial model. Careful camera parameter estimation may be ommissible in many cases.

In the second stage, local mesh modification is made if necessary to cope with the occlusion problem inherent in the method. This local mesh adjustment, manually by observation or by measurement using active methods, such as the laser triangulation sensor, serves accuracy improvement.

As an example, an initially constructed model of a male sculpture is transferred to that of a female sculpture by modifying the geometric coordinate values of the mesh points based on the multi-directional images of a female sculpture that is to be modeled as an approximation. This enables the initial model of the male reusable to all kinds of human sculptures. Then a simple cylindrical model, having quadrilateral meshes is transferred to another model of a mannequin dummy by the similar procedure.

The procedure replaces the laborious modeling of the object from the beginning, starting only from the simple cylindrical model with desired meshing. Conserved quadrilateral meshes can omit the mesh generation process in numerical analyses such as FEM and BEM. Number and shape of the mesh are assigned to the initial model prior to the measurement.

2. Method
The principle of the conventional method of 3D shape approximation and modeling, so-called “silhouette pyramid intersection method,” is summarized as follows. In the first stage, a silhouette of the new object, that is a boundary of the object image, is extracted. The boundary is approximated by a polygon. This is shown as a polygonal figure in each view plane, for instance, a quadrilateral figure in a plane PL1 in Figure. 1. It consists of vertices having linkage information.

In the second stage, a semi-infinite pyramid PM1 is constructed from a polygonal boundary in PL1 and the center of perspective, for instance, C1 in the figure. In this pyramid, a vertex is the center of perspective and a cross section is the polygonal silhouette. When multi-directional images are acquired, a corresponding number of semi-infinite pyramids are generated in the same way.

In the third stage, intersection of all of these multi-directional pyramids or, in other words, the Boolean calculation of the common region of all of these pyramids generates a polyhedron. When the object has a convex shape, this polyhedron becomes a progressively better approximation to the original shape as the number of view directions increases. If the object is not a thoroughly convex form or the substantial number of the directions is not large enough, this polyhedron may be used as an approximation within acceptable engineering accuracy.

After the multiple pyramids are generated, a wire-frame model for the intersected region, a poly-
Fig. 1  Principle of model generation from multiple views.  

Fig. 2  Solid model of a lemon.  

Fig. 3  A geometric model of a male sculpture.  

Fig. 4  Multi-directional images of a female sculpture acquired in every 3 degrees.
Fig. 5   A female sculpture model transferred from the male model in Fig. 3.

Fig. 6   A cylindrical model having 40 peripheral segments in every 9 degree spacing and 60 vertical elements.

Fig. 7   Multi-directional images of a mannequin dummy acquired in every 9 degrees.
Fig. 8  A geometric model of a mannequin dummy transferred from the cylinder in Fig. 6.

hedron to approximate the object, is generated and then transferred to a surface model. Finally, the surface model is transferred to the so-called solid model. This solid model is in the form of a polyhedron, which is consisted of its vertices and facets. Each vertex is defined by its geometric x-y-z components and each facet is defined by the linkage information of the vertices.

In the solid modeling, not only the linkage relation of the facets and vertices that defines the polyhedron, but also the direction of the linkage sequence that defines the direction of the normal vector of the facet is involved. With this it is possible to determine on which side of the facet the solid part of the object exists. This reconstruction procedure will be replaced by employing some alternative methods such as CAD systems.

In this modeling, three-dimensional position of each vertex is described by a single coordinate system, which is defined by the coordinate when the camera parameters are initially calibrated. If the center of perspective is far from the object, the projection becomes parallel [7].

A sculpture of a female head is set on a precisely indexed rotating table and its image is acquired by a digital video camera of, for instance, 640 x 480 pixels resolution. The sculpture is rotated in an adequate angle or, for instance, 3 to 9 degrees in an equal interval of angle, around the table axis. The initially constructed geometric model of the male is also rotated in the corresponding angle in the computer. Each silhouette, viewed from each direction of the angle, is compared arithmetically or graphically on the monitor screen. Geometric values of the mesh points of the initial model are modified so as to match the silhouette of the acquired image. If the initial model has line segments, parallel to the axial line is a part of a silhouette viewed from a corresponding direction. The line to line angle is set to the rotating table, contradictorily.

The demonstration is substantially the silhouette pyramid intersection method, from the point of view of the shape measurement, but it differs from the point of the topological view. In the method, an initial polyhedron is transferred to another polyhedron having the same number of meshes and the same mesh point connectivity. In this method the vertex connectivity in each mesh is unchanged. But the geometric coordinate values of each mesh point are modified so as to match the new object shape.

The initial polyhedron is made or designed prior to the reconstruction procedure. If we construct the initial model where the silhouette is visible in each angle of direction, the mesh point modification becomes easy. For instance, if the spherical or cylindrical model is used as the prototype, the meridian corresponds to each silhouette.

In the method concave regions, for instance, eyes that are occluded and invisible from any directional silhouettes are unable to reconstruct. These regions have to be locally modified according to the adequate position measurement.

3. Results and Discussion
As an example, a geometric model of a male
sculpture [8] is shown in Fig. 3. The male model is modified and transferred to a female model, based on the multi-directional images of the female sculpture. Examples of the multi-directional images are shown in Fig. 4. The resulted female model is shown in Fig. 5. In this model transfer, the female sculpture is rotated in every 3 degrees. Additional angles are, if required, set according to the mesh line parallel to the rotating axis. Then some mesh points around the eyes are locally modified. It is observed that the model resembles the sculpture in shape.

A simple cylindrical model is constructed with an equal angular spacing of 9 degrees, consisting of 40 radial line segments. Vertically it has 60 segments. Each mesh shape is quadrilateral. Total number of the mesh is 2,400 as shown in Fig. 6. The meridian of the model is compared with that of the corresponding mannequin dummy on the table in every 9 degrees. Multi-directional mages are shown in Fig. 7. The transferred model is shown in Fig. 8.

As shown in Fig. 5, a male model has been transferred to a female model with quadrilateral meshes of the same vertex connection. The model is easy to understand than that obtained solely from the silhouette pyramid method, for instance in Fig. 2.

Laborious model construction process from the beginning is omissible when human models are concerned. The procedure enables to reconstruct various approximate human models from this single prototypal model.

Geometric parameters such as x, y, and z values or r, θ and z values are modified, but the connectivity of the vertices in the mesh remains unchanged. For numerical analyses such as FEM and BEM, we can select types of mesh shapes in the initial model, such as triangular, quadrilateral, hexagonal and/or n-gonal mesh. No further re-meshing is necessary [4]. In some numerical analysis, calculation procedures that are prepared for the initial model may be used only by editing the geometric coordinate values.

As for the geometric model of a mannequin dummy, a simple cylindrical model is usable instead of the laborious construction of the dedicated geometric model. The simple cylinder can be transferred or warped to the various types of the objects if they are measurable using the single axis rotation. Variously sized meshes are locally usable fitting to the local curvature of the object surface.

4. Concluding Remarks
A geometric modeling that modifies the geometry of the initial prototypal model is proposed. This model modification only of the geometry and not of the topology will bring together the reuse of the initial model and the ease of modeling, starting from a simple geometric model with desired meshing. An example of a male model transfer to a female model and a simple cylindrical model to a mannequin dummy model are demonstrated. Shape approximation and simultaneous mesh generation for numerical analyses will be brought by. Fully automated system construction for this modeling is our present problem, combining with the point wise position measurement. We expect some considerable utility in the practical geometric modeling.

References: