Tri-Dexel Volumetric Modeling for Haptic Sculpting and Virtual Prototyping of Complex Surfaces

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ABSTRACT
This paper presents a new tri-dexel volumetric modeling method for representing complex geometric models in applications such as haptic virtual sculpting and product prototyping. A tri-dexel model consists of three overlapping dexel models in X, Y, and Z axis directions, respectively. Detailed algorithms of eliminating inconsistency in a tri-dexel model and reconstructing a water-tight polyhedral surface model from a tri-dexel model are discussed in this paper. Compared to the traditional voxel model data structure and dexel model data structure, the proposed tri-dexel data structure provides a better alternative geometric modeling method for certain applications. The proposed techniques can be used as a geometric representation kernel in CAD/CAM systems and CNC process simulation.

KEYWORDS
Tri-Dexel Modeling, Haptic Sculpting, Virtual Prototyping, CAD/CAM, CNC Simulation

INTRODUCTION
The volumetric representation of geometric models has advantages in 3D scanning data processing, heterogeneous material modeling, and other applications that require simple Boolean operations at interactive speed, e.g., haptic virtual sculpturing and CNC process simulation. Several types of volumetric models, such as the voxel model [1] and the dexel model [2], have been proposed in the earlier research. A voxel model represents an object with many small cubes in a regular lattice, as shown in Figure 1(a). It is used extensively in Volume Graphics [3]. A standard voxel model has the limitations of being unable to conserve accurate geometrical and topological feature information, especially at sharp edges and corners. A dexel model represents an object with a grid of long columns compacted together along a certain direction, as shown in Figure 1(b).

Compared to a voxel model, a dexel model requires less memory space and may provide higher accuracy along the dexel orientation. However, dexel models also have some limitations, i.e., the sampling quality may be low at surface regions where the surface normals are perpendicular or nearly perpendicular to the dexel orientation. The tri-ray model proposed by [4] has the advantage of accurately representing smooth surface models. Its visual representation is similar to the tri-dexel as in Figure 1(c). However, the sensitive features (e.g., sharp edges) cannot be retrieved from a tri-ray model. The modeling inconsistency problem existing in tri-ray models has not been solved in the past research [4,5]. Kobbelt [6] proposed enhanced distance field representation and an extended Marching Cube algorithm to keep the sensitive features in the volumetric data. The extended Marching Cube algorithm, which is applicable to the voxel model only,
does not provide an efficient method for Boolean operations, which is very important in time-critical applications such as real-time haptic virtual sculpting [7]. Therefore, it is of interest to seek for a new volumetric representation that can both represent accurate geometry and achieve fast model updating.

Polyhedral surface representation has been widely adopted in the Computer-Aided Design and Manufacturing (CAD/CAM) systems for 3D modeling, Reverse Engineering and CNC tool path generation. One common polyhedral surface model is STL (Standard Transformation Language) model, which represents an object with triangular facets [8]. In our earlier research work presented in [7,9,10], a virtual sculpting system with a 5-DOF (degree-of-freedom) haptic interface has been developed for virtual prototyping and machining planning. In our earlier system [9,10], a dexel-based in-process modeling method was adopted and visibility sphere marching algorithms were proposed to convert a dexel model to a polyhedral surface model [11].

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REFERENCES


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