

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.

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KEYWORDS

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

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INTRODUCTION

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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 sculpting and CNC process simulation. Several types of volumetric models, such as the voxel model [Wang 95] and the dexel model [Van Hook 86], 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 [Kaufman 93]. 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 Benouamer 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 [Benouamer 97, Tobler 96]. [Kobbelt 01] 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 [Ren 06]. Therefore, it is of interest to seek for a new volumetric representation that can both represent accurate geometry and achieve fast model updating.

MODELING OF THE PLANT
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The high-precision measurement machine under investigation consists of five precision servomechanisms, three of which are used to tightly control the position and force of a probe used to measure a parts dimensions, and two of which are used to center the part in the measurement volume. Detailed modeling of respective axes has been done in (Tarbutton 2007). The axis used in this paper is a frameless rotary brushless DC motor suspended on air bearings.

A model for this servo mechanism is shown in #

Figure 1. The Laplace transform of the differential equations of the DC motor plant yields the transfer function shown in Eq. **Error! Reference source not found..**

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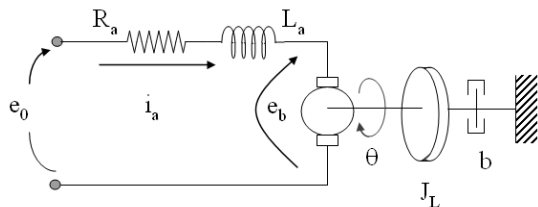


Figure 1. Plant model.
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Pole Placement
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The controller gains that give the desired pole locations can be found by creating a polynomial with the desired poles and equating the coefficients of this polynomial to the coefficients of the seventh order polynomial denominator in Eq. **Error! Reference source not found..** Because both polynomials are monic there are six equations relating the coefficients. The coefficients of the denominator in Eq. **Error! Reference source not found.** are in terms of the three unknown gains, K_p , K_I , and K_D . Four of the pole locations are specified by the desired performance characteristics and constraints of the system; the other three poles are unknown. Therefore, the three unknown poles and three unknown gains are determined by solving the six equations relating the coefficients of the polynomials. Therefore, only two of the poles can be uniquely placed, two are fixed at 0 and 1, and the other three are determined

by solving the equations. The K_p , K_I , and K_D gains are uniquely found by specifying four of the pole locations. A MATLAB program was used to solve for the gains and remaining pole locations.

Chip Formation. Understanding the formation of chips provides helpful information on the abrasive material removal processes such as grinding and micro machining. Depending on the chip formation, forces vary in different directions. Kita et al. (1978) investigated the mechanism of chip formation in conical tools. They identified five different characteristic regions during the cutting as shown in Figure 4: (a) a region removed as a chip, (b) a stagnant region beneath the tool face, (c) a highly deformed region which flows up to form the chip, (d) a region that deforms and flows down or along the side of the stagnant region, and (e) the region that does not deform. According to this model, the position of the stagnant tip and the volume of the stagnant region change continuously. The formation of the chip is determined by the position of the stagnant tip; and consequently, the chip formation is an intermittent process. This causes significant variations in cutting and thrust forces.

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Table 1. Flow stress and friction coefficient for different depths.

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Depth of Cut (μm)	5	10	15
F_c (N)	0.018	0.064	0.14
F_T (N)	0.037	0.14	0.31

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ACKNOWLEDGMENT

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The research is based on the work supported by the National Science Foundation under Grant No. CMMI-0447452.

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