Interactive Visualization of Non-manifold Implicit Surfaces Using Pre-integrated Volume Rendering

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Abstract

We present an interactive method of visualizing both manifold and non-manifold implicit surfaces. The implicit surfaces are directly visualized at interactive frame rates independent of surface complexity by the hardware-accelerated volume rendering method. Although conventional implicit surfaces can represent only two-manifold surfaces, we have developed a technique of representing non-manifold surfaces as implicit surfaces by applying segmented distance field. Implicit surfaces represented by this definition can be rendered by pre-integrated volume rendering using vertex generation diagrams as pre-integration table. We also developed a system for visualizing the implicit surfaces and have confirmed that it can render surfaces at sufficient quality and speed.

Keywords: implicit surfaces, non-manifold, segmented distance, vertex generation diagram, volume rendering

1 Introduction

Traditionally implicit surfaces are limited to two-manifolds because the corresponding implicit fields are usually defined by a real-valued function which bisects space into interior and exterior. A typical example of the function is the *signed distance*, which assigns a real-valued distance with a positive sign when the point in the space is outside the region enclosed by the implicit surfaces, and with negative sign when the point is inside the region. The surface models represented by the signed distance field must have incorrect topology and geometry if the surface has boundaries or intersections, where the space cannot be bisected.

This problem can be solved by applying multiple classification of implicit fields. Recently, we proposed a method of handling non-manifold surface models as implicit surfaces using *segmented distances* which enable multiple classification of space according to the topology of the given surface [2]. In this paper, we propose a technique of visualizing manifold and non-manifold implicit surfaces by applying our proposed approach to the method of slice-based volume rendering.

2 Non-manifold implicit surfaces

Non-manifold implicit surfaces can be defined as implicit surfaces which are not manifold. This definition, however, is undesirable because the isocontour of a real-valued function can be degenerated into points, lines, or volumes, which cannot be regarded as "surfaces". Therefore we explicitly define non-manifold surfaces as a set of 2-manifold surface patches connected on their boundaries. Using this definition, triangular meshes or parametric surface patches can be used to represent non-manifold surfaces.

In order to handle surface boundaries and junctions, we applied the segmented distances which enable multiple classification of space. First, surfaces are divided into patches along the diverging lines. For each face for each patch, a different index is assigned. The distance function $f(p)$ for point p in the field is defined by both the index $n(p)$ of the nearest point and the distance $d(p)$ to the nearest point using the equation

$$f(p) = min(D, d(p)) + D \cdot n(p) \tag{1}$$

where D is a sufficiently large number. The function f can be regarded as the distance with the offset $D\dot{n}(p)$ assigned to each region.

The isocontour of the segmented distance field can be extracted by interpolating the distances. The interpolating parameter q of the isosurface between adjacent sample points whose values are u and v is determined by

$$q = \begin{cases} \dfrac{u - r_i}{(u - r_i) + (v - r_j)} & \text{if} \quad \begin{array}{l} u \in [r_i, r_i + d], \\ v \in [r_j, r_j + d], \\ 0 < (u - r_i) + (v - r_j) < w, \end{array} \\ 0 & \text{otherwise,} \end{cases} \tag{2}$$

where $i, j = 1, \ldots n$ and $i \neq j$. $q = 0$ means that there is no isosurface between the sample points.

The calculation of equation (2) becomes complicated particularly when the number of segments n is large. Therefore the calculation can be accelerated by tabularizing it into a two-dimensional chart called *vertex generation diagram*. An example of multiple classification using the segmented distance and corresponding vertex generation diagram is shown in Figure 1.

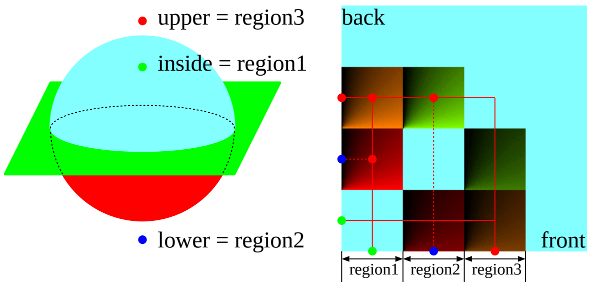

Figure 1. Left: Multiple classification for non-manifold implicit surfaces. Right: Corresponding vertex generation diagram.

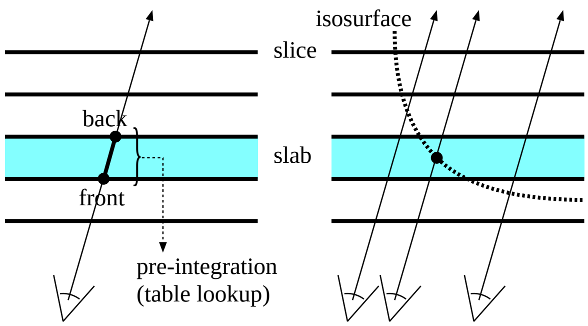

Figure 2. Left: Slab-by-slab accumulation in pre-integrated volume rendering proposed in [1]. Right: Continuous surface extracted from discretely sampled distance field.

3 Pre-integrated volume rendering

Recently Engel et al. [1] proposed the method of high-quality volume rendering by calculating the accumulation of color and opacity between sample points in advance. In this method, the volume is partitioned into a set of slabs which are the thin volumes occupying the space between adjacent slices, as shown in Figure 2. When the ray intersects a slab, it intersects the front and back slice once for each. The integral for the pair of the voxel values is calculated numerically, then accumulated slab-by-slab in the back to front order. If the value of distance field is discretized, the integration of every combination of field values can be stored in a lookup table.

Although this pre-integration is a general method of volume rendering, it is suitable for the visualization of implicit surfaces. As for the visualization of non-manifold surfaces, our approach of using vertex generation diagram is well suited because the diagram is equivalent to the pre-integrated table. Uploading the vertex generation diagram as the table of pre-integration therefore allows visualization of non-manifold implicit surfaces.

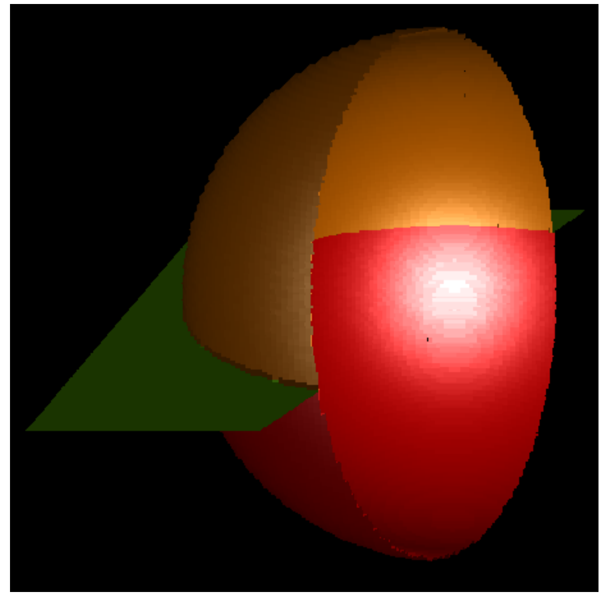

Figure 3. Non-manifold implicit surface of model in Figure 1 visualized by volume rendering. Half of the model is visualized for explanation.

4 Experimental result

Volume rendering based on the method proposed in [1] was implemented on a standard PC equipped with GeForce4 GPU. To avoid undesirable interpolation of segmented distances, linear interpolation of volume was disabled.

The results of rendering a non-manifold surface model with boundary and junction are shown in Figure 3. The drawing could be performed at interactive frame rates.

5 Conclusion and future work

We have presented an interactive method of rendering non-manifold implicit surfaces by hardware-accelerated volume rendering. One difficulty in this method is the generation of segmented distances and calculation of distance from the given surface model. The analysis of more complicated cases will be taken up in future work.

References

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