Surface Shape Perception in Volumetric Stereo Displays

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Abstract

Research have shown that specifically designed textures applied on geometrical surfaces can greatly enhance human perception of the shape, orientation and spatial relationships of the surfaces [12]. This is especially so for surfaces in a stereoscopic display environment [2]. However, virtually all practical systems of volumetric rendering use no texture.

Previous studies that have looked at this issue used either simple 3D surfaces or terrain surfaces. In this work, we explore the application of textures to more complex surfaces that come from various sources, e.g., an isosurface extracted from a volume dataset. The challenge is to generate uniformly distributed grid-like textures on complex surfaces that naturally follow the geometry of the surface.

We incorporate the texturing method directly into a fast volume rendering process [6] to enhance the perception of complex surfaces present in a volume dataset. To measure the effectiveness of the texture, we conduct user studies where user is asked to orient a probe to give the estimate of the surface normal at the probe attachment position which will be compared with true surface normal direction.

Line Texture Generation

1. Use Marching Cubes [3] to generate the isosurface of interest.
2. Use the Ellipsoid Method [4] to generate the minimum convex hull of the isosurface. (Figure 1a)
3. Use Catmull-Clark subdivision [5] to generate a spherical shape from a unit cube. (Figure 2)
4. Use affine transformation to match the two shapes in the previous steps. (Figure 1b)
5. Push all edges of the subdivision surface towards the geometric center of the isosurface.
   a. For each line segment, generate a triangle by connecting the isosurface center with the end points of the segment. (Figure 3)
   b. Compute the intersections of the constructed triangle with all triangles of the isosurface. The intersections are line segments and effectively form grid-like evenly distributed line texture on the isosurface. (Figure 1c)

Line Texture in Volume Raycasting

After the line texture is generated, it is then used in a direct volume raycasting process (Figure 1d).

In ray-casting, dim the pixel color if the ray (Figure 4):
1. Goes through the line texture and,
2. Reaches a sample value that is close to the one used to generate the isosurface.

Experiment

Apply gabor function with random parameters to unit sphere to generate randomly transformed spherical shapes (denoted as gabor surfaces).

Convert gabor surfaces into signed distance fields which are used in volume rendering. Randomly select several points on each gabor surface as probe attachment positions.

Each experiment involves three randomly chosen gabor surfaces and the human skull with each shape providing five attachment points. Each attachment point is further expanded into five instances with five different line texture opacities. This all together gives 100 instances of different attachment point and line texture opacity combinations which are randomly shuffled to give an experiment sequence.

For each presentation, users are required to orient a probe to give their estimate of the surface normal at the probe attachment position (Figure 5). Of the three gabor surfaces, one is displayed in front of the virtual screen, one is displayed behind the virtual screen and one is displayed with center point right on the virtual screen.

References


Figure 5 – Examples of Gabor Surfaces and Probes