Evaluation of Image Quality in Particle-based Volume Rendering

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Abstract

In this paper, we evaluate the quality of images which are generated by using our particle-based volume rendering (PBVR) technique. We develop a technique for generating an image which is equivalent to a volume ray-casting image in the PBVR. First, we calculate a particle density from a transfer function and a length of the ray segment, both of which are actually used in the volume ray-casting calculation. Then, we estimate number of particles to be generated by integrating the density function over the whole volume region. We applied the PBVR technique and a volume ray-casting technique to the same volume datasets, and confirmed that the image quality is gradually improved according to the increase of the number of generated particles.

1. Introduction

Since the scale and complexity of volume datasets is increasing, there is a strong demand for volume rendering techniques capable of handling huge and complex volume datasets. To render such volume datasets with conventional volume rendering techniques, the calculations required for sorting and alpha blending can become a bottleneck.

To solve these problems, we previously proposed a particle-based volume rendering (PBVR) technique that can be effectively utilized to render various types of volume datasets, either regular or irregular. In the PBVR technique, a set of tiny, non-transparent particles is generated in a given 3D scalar field with a stochastic technique. Then, we project these particles onto a frame buffer to generate an image with z-buffer depth [8].

Recently, volume rendering technique which uses points as rendering primitives has received increasing attention and is a topic of ongoing research. Hopf and Ertl proposed the use of a hierarchical data structure based on PCA clustering procedure in order to accelerate the visualization of scattered point data [5]. This data structure enables fast sorting of semi-transparent clusters and may therefore trade rendering speed for image quality. The image is obtained by traversing this structure for each frame. In addition, the use of quantized relative coordinates reduced the memory consumption. For a semi-transparent realization, their technique requires alpha blending which requires the points to be sorted according to their projected z coordinates.

The proposed particle-based volume rendering technique represents the volume data as a set of particles. The particle density is derived from a user-specified transfer function and describes the probability that a particle is present at a given position. Since these particles can be considered to be fully opaque, no alpha blending is required during the rendering calculation, which is advantageous in the distributed processing. Csébfalvi proposed a similar technique [2] [1] that can be categorized as X-ray volume rendering, in which the number of points on the image plane is simply counted, but the luminosity of the points is not considered.

Although PBVR paves the way for dealing with huge and complex volume datasets, a key issue is to confirm that PBVR can produce the same quality of images as a typical volume rendering technique of a volume ray-tracing technique. In PBVR, we generate particles according to a specified density field derived from a transfer function. In this paper, we apply our technique and a volume ray-casting technique to the same volume datasets, and confirmed that the image quality in our technique improved according to the increase of generated particles in number.

After we describe an overview of our PBVR technique in Section 2, we introduce a way of calculating a density function which can generate the same image as a volume ray-casting technique. In Section 4, we show the error distribution results in images generated by PBVR and volume ray-casting techniques.

2. Overview of PBVR

Our particle-based volume rendering represents a 3D scalar field as a set of particles. In general, volume rendering techniques utilize an illumination model in which the 3D scalar field is characterized as a varying density emitter with a single level of scattering. This model is related to a particle model in which the size of the particle is small for the radius of the viewing ray, that is the pixel size. A conventional volume rendering technique models the density of particles, not the particles themselves. That is, a given scalar field is described as a continuous semi-transparent gel, and the accumulating order is important. This results in a considerable computational overhead.

Our particle-based volume rendering is composed of three phases: particle generation, particle projection, and subpixel processing. The first phase is to construct a density field and to generate particles according to the density function. The second phase is to project particles onto an image plane. The third phase is to divide a single pixel into multiple sub-pixels so that a particle is stored as precisely as possible, and to calculate a final brightness value using sub-pixel values [8]. These phases are described in detail in the following subsections.