Complex-Valued Multiresolution Volume Rendering in 3D Imaging

I Provaznik, D Schwarz, P Fedra

Brno University of Technology, Brno, Czech Republic

Abstract

A number of techniques have been proposed for rendering volumetric data sets. A modern approach lies in the use of a hierarchical description of images that are decomposed into a sequence of multiscale representations. Discrete-time wavelet transform (DWT) is often used for the decomposition. This approach is similar to that used in computer graphics where scenes are utilized in structures called octrees. A ray-casting based method using complex-valued DWT has been proposed to serve as a rendering technique for visualization of medical images from various modalities such as CT and MR.

1. Introduction

3D medical visualization is the process of generating a visual representation of the information contained in abstract data fields resulting from measurements by various modalities. The standard model of this process comprises of three steps. First, raw data is filtered in a preprocessing step to generate visualization data which is usually reduced by operations like sampling. Second, the abstract data field is mapped into a visual representation consisting of geometric primitives like points, lines, surfaces or voxels and associated graphical attributes like color and transparency. Third, the scene description is used to generate images by means of a renderer.

The 3D scene can be only be visualized by generating 2D images. A number of methods have been developed to cope with the problem which possesses many constraints. Typically, two main constraints of maximum interpretation quality and minimum computation complexity are followed in medical applications.

One of the well known method is ray-casting. Although it suffers from high computational complexity, it can be effectively used to render 3D medical images from various modalities. Also, the method can be extended to obtain more precise rendering at the same computational load as proposed in the paper.

2. Methods

Ray-casting is used to render opaque surfaces directly without forming an intermediate surface representation of polygons. This allows the method to work without a need of additional global algorithms such as segmentation and interpolation.

2.1. Ray casting

Ray casting is one of the powerful volume rendering techniques. Rays are casted from each pixel of the image plane into the volume data (see Figure 1). At locations along each ray a sample value and a surface normal approximation are calculated using values of surrounding voxels. Using the sample value and normal, a sample opacity is dynamically assigned by a look-up table. Then, a local shading model is applied and the samples along the ray are composed into a pixel value of the final image [1, 4].

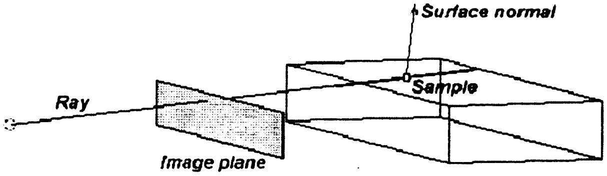

Figure 1. Principle of ray casting.

The method can be implemented with various definable parameters. One of them is a sample rate along a ray. Resampling the scalar function causes that the samples are at non-integer positions. Local tri-linear interpolation is used to estimate the sample value. The same technique is used for gradient estimation (surface normal computation). The sampled nature of volumetric data causes that we approximate it by local differences between sample values in all three dimensions.

Local shading model is used to compute intensity reflected by the sample from the light source towards the image plane. The theory of light transport is simplified here. The ray from the light source to the sample is not affected by intermediate voxels. On the other hand, this kind of interaction is considered along the ray to the image plane by composition. The Phong illumination model used here describes the intensity reflected by the sample as [5]:

$$I = I_a + \sum_l I_l \left[k_d \vec{N} \cdot \vec{L_l} + k_s \left(\vec{R} \cdot \vec{V} \right)^n \right] \qquad (1)$$

where I_a is the reflected intensity due to ambient light, I_l is the light source intensity, k_d is the material diffuse reflection coefficient, k_s is the material specular reflection coefficient, n is the material specular reflection exponent. The meaning of the vectors is described in the Figure 2.

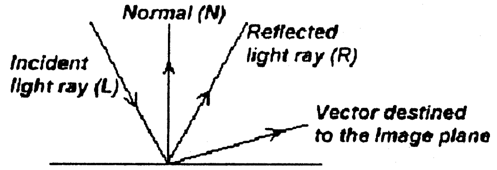

Figure 2. Vectors used in the Phong illumination model.

The intensity C along the ray s can be computed as [3]:

$$C(s) = \int_{s_0}^{s} q(s') \cdot \exp[-\int_{s_0}^{s'} \alpha(s'')ds''] \cdot ds' \qquad (2)$$

where q is the emission and a is the absorption. The discretization of this integral leads to the compositing formula:

$$C = \sum_{k=1}^{n} q_k \alpha_k \prod_{i=0}^{k-1} (1 \cdot \alpha_i) \qquad (3)$$

The reflected intensity I from (1) can be substituted for q_k in (3). The opacity a_k is derived from a look-up table after interpolation of the scalar value.

2.2 Adaptive termination

Ray casting with pseudocoloring and gradient magnitude modulation is very computation intensive process. The goal of adaptive termination is to shorten the rendering time. It is done by finding the last sample along the ray, which affects the resulting intensity (or color intensities) significantly. A simple criterion $C_{out} - C_{in} > Epsilon$ is used here.

2.3 Enhancing images for interpretation

More comprehensible images are obtained when the various tissue are displayed with different optical properties. It can be done by using two techniques: pseudocoloring and gradient magnitude modulation.

For pseudocoloring different objects we need to know their value ranges in the data. This can be easily done with CT images but in MRI data same values can appear in different tissues.

Based on image histogram, a simple classification function is used for computing opacity and color look-up tables. After interpolation of the scalar value, an opacity value and a color determined by an RGB triple are assigned to the sample. Then, lightning equations for each color in the Phong illumination model (1) are used.

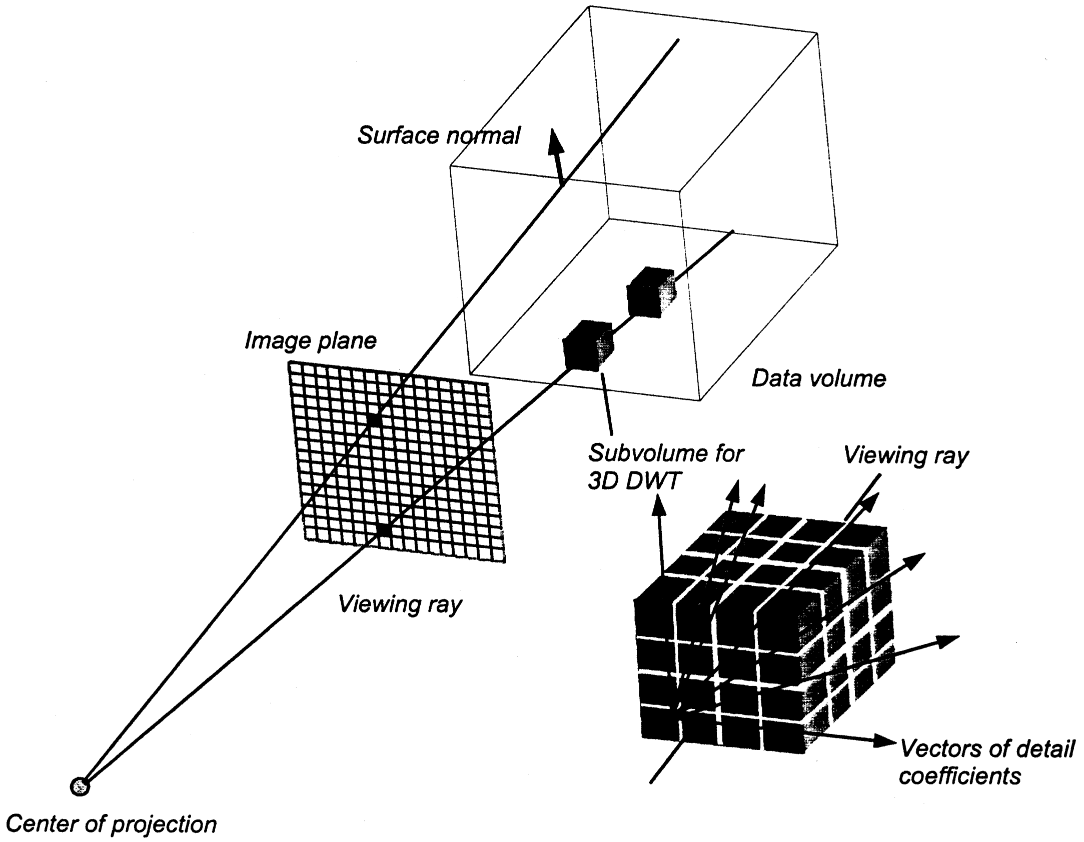

Figure 3. Principle of ray casting using multiresolution division scheme.

With the simple histogram-based segmentation procedure, color images containing various types of tissues can be rendered. For imaging semitransparent images with information about several types of tissues, surfaces of visualised objects have to be pointed up and homogeneous regions have to be suppressed. For this purpose we use gradient magnitude modulation. Simple multiplication of the gradient magnitude and the opacity value results in smaller color contribution of the voxels in the homogeneous regions and vice versa. We boost up this process by assigning gradient magnitude value also from a look-up table with partly constant and partly linear transfer function. Thus, resulting semitransparent images are better perceived as it was experimentally verified.

2.4 Wavelet division scheme

The ray casting method is modified with the use of a multiresolution division scheme [10]. The division scheme describe local preprocessing of subvolumes around each sample of currently processed ray. Originally, all rays must be sampled at sufficiently high rate to obtain good approximation of a intensity integral (2). This leads to extremely high computation times.

Multiresolution division scheme allows to sample each ray more roughly within whole data volume (low rate). The idea is that subvolumes between samples are decomposed to obtain their multiresolution representation [9]. Then, the representation is exploited to find local surfaces within the subvolume. It is obvious that subvolumes with found local surfaces must be resampled at standard rate while subvolumes with no local surfaces are skipped.

To obtain multiresoluton representation, complex-valued 3D discrete wavelet transform is computed on voxels adjoining each sample. A realistic scheme uses low rate at e.g. 1/8 of standard rate. Then, subvolumes to be decomposed should be cubes of about 8^3 voxels. This scheme keeps additional computation complexity below that saved by downsampling the rays. 3D wavelet transform generates other eight subvolumes of 4^3 voxels representing wavelet coefficients. One of the subvolumes represents approximation coefficients while seven other represent detail coefficients. Details indicate changes (surfaces) within the original subvolume in seven different volume directions.

Magnitude of complex-valued wavelet coefficients are thresholded to find significant changes in one of the seven sets of detail coefficients [8]. As we are computed on a ray of certain direction, we are interested in changes in the corresponding detail coefficients. Found values higher than chosen threshold are therefore weighted with respect to azimuth and elevation of the ray and summed.

If local surface is found, the ray is resampled at standard rate to obtain more precise rendering in such regions of interest.

3. Conclusions

In the paper, a method of volume rendering of opaque and semitransparent surfaces without forming an intermediate surface representation of polygons is proposed. The method involves wavelet-based division scheme that uses two rates of ray sampling. Computational complexity of the new method is not higher than that for original volume rendering method using lower rate of ray sampling in regions of low interest. Images are more precisely rendered at the surface locations using higher rate of ray sampling. Both rates can be arbitrarily chosen to obtain quality of rendered images most proper to the application.

The method may be applied on image data from various modalities. Previous tests have been done on CT and MR data from Visible Human project, NLM, USA.

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Address for correspondence.

Ivo Provaznik
Department of Biomedical Engineering
Brno University of Technology
Purkynova 118
61200 Brno
Czech Republic
ivo@ieee.org