Non-Photorealistic Volume Visualization with Color Distance Gradient and Two-Level Volume Rendering

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Abstract

Traditional approaches for rendering photographic volumetric data sets usually use the original color from data set. But for some complicated medical object, it delivers unsatisfactory results. In this paper, we proposed a novel non-photorealistic volume rendering (NPVR) technique, color distance gradient for opacity design and two-level volume rendering, based on graphics processing unit (GPU) accelerated raycasting, to address this problem. Segmentation information is adopted to enhance the performance of visualization and special structure can be highlighted in the volume according to user's feedback. Visible Human Project (VHP) data set is used for test and the result confirms that our method is effective.

1. Introduction

Volume rendering has been widely applied to industry, astronomy, and medical field for its capability of exploring the detailed information in volume data directly without first resorting to the geometry of triangles. Direct volume visualization is popular for the best performance. Several photographic data sets are provided for further research, and one of the most popular data sets is Visible Human Project (VHP) at the National Library of Medicine, which is very valuable for medical illustration, pathology research, surgery simulation and so on. As for VHP data set, although color design can be omitted, the opacity design is more difficult and complex than gray image data set [2]. Ebert presented a good visualization result based on color gradients [1][2]. In [3], Liu provided some better results based on a combination of transfer functions based on color distance gradient and GPU is adopted for acceleration.

Volume classification may be an important tool for volume rendering. Sereda et al. introduced the LH space as transfer function domain which proved to be an effective way for volume classification [4]. After that, Praßni provides an acceleration approach [5]. We also achieve a new way for visualization of collection from VHP based on voxel's frequency in LH Histograms [6].

For decades, medical visualization has pursued absolute visual realism and almost excluded all other considerations. Recently, direct volume rendering was also used with non-photorealistic volume rendering (NPVR) techniques to enhance the perception of object structures and texture orientations [7]. Instead of generating photorealistic images, NPVR attempts to enhance underlying features and important cues for surgeons via stylized rendering in non-photorealistic forms.

In the paper, we provide a new way for photographic volumetric data set. NPVR is used for enhance underlying features and color distance gradient is used for opacity design. Also two-level volume rendering [8], which allows for selectively using different rendering techniques for different subsets of a 3D data set, is taken to enhance the segments. We use GLSL (OpenGL Shading Language) for the GPU's acceleration.

The organization of this paper is as follows. Section 2 gives the overview of our work, and describes the process pipeline for visualization. The label-based classification algorithm is presented in Section 3. Opacity design is also discussed in this section. Non-Photorealistic volume rendering is described in Section 4, where a novel method of color histogram equalization is presented for color difference enhancement. Two-level volume rendering is outlined in Section5. Finally, the experimental result and conclusion will be given in section 6 and section 7 respectively.

2. Overview

The key idea of this work is the synthesis of 3D volume textures. Specifically, our algorithm involves three phases and the process pipeline is shown in Figure 1. The basic procedures are as follow.

1) Firstly, object segmentation is done and furthermore, mask volume data is built based on the segmentation result.
2) In the second step, effective transfer function is

presented, in which NPVR is used to enhance underlying features and color distance gradient is used for opacity design.

3) In the last step, we put the processed volume texture into OpenGL pipeline. The two-level volume rendering is taken in this stage.

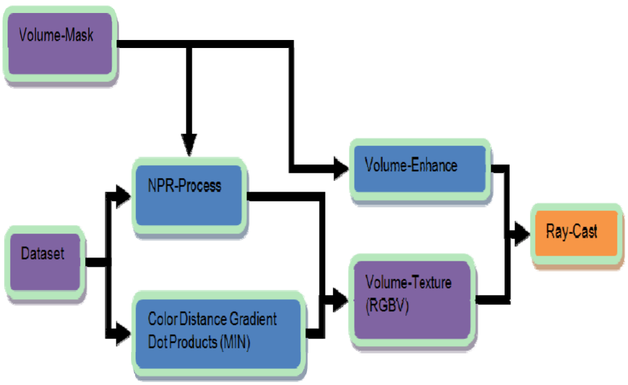

Figure 1. Process pipeline.

3. Label-based classification

In this section, we use the popular label-based classification procedure for segmented 3D volume [9]. Figure 2 describes the solution that is generally used for voxel classification with mask label.

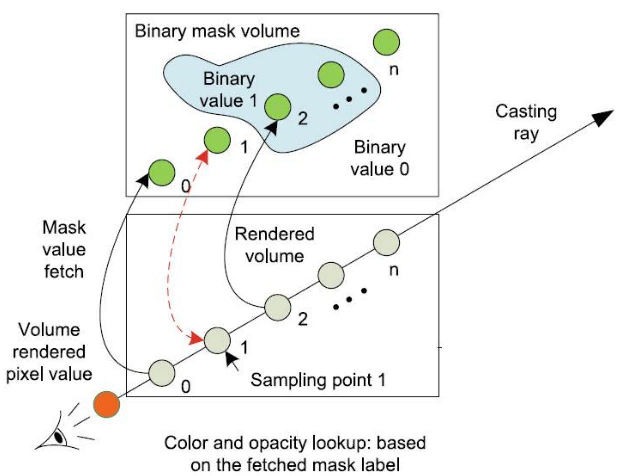

Figure 2. The segmented 3D volume rendering pipeline.

Our method is simple but effective. First, at each voxel, put the mask information, which is an integer, into the V component of the volume texture, while if the anatomical region is not interest, give 0 to the V component, which will be skipped while rendering. Furthermore, voxel should be allocated color and opacity attributes.

As for opacity design, we adopt Color Distance Gradient Dot Products (MIN) in [3], and the method can be described as follow.

The color distance gradient vector D(x,y,z)is given by

$$\nabla(I_g) = (I_{gx}, I_{gy}, I_{gz}) \quad (1)$$

where ∇x , ∇y, ∇z denote x,y and z components respectively of color distance gradient vector. So the color distance gradient magnitude is then given by:

$$CDGM = \|D(x,y,z)\| = \sqrt{(\nabla x)^2 + (\nabla y)^2 + (\nabla z)^2} \quad (2)$$

In order to highlight voxels with small angular color changes, we can adopt the 6 adjacent neighbor voxels which also have large gradients for opacity design by

$$V = MAX_{i=1}^{i=6}\left[\left((Grad(voxel) \bullet Grad(neighbor)\right) \times \|Grad(voxel)\|\right] \quad (3)$$

As for photographic volume visualization, the original color of voxel can be used, and color design tends to be omitted in previous works. However, most medical organs have complicated structure and different structures often have similar colors, which can cause some confusion for surgeons. In this paper, NPVR is used for the improvement of visualization performance. Our basic idea is to enlarge the differences of different structures in color space.

4. Non-photorealistic volume rendering

For the photorealistic volume rendering, because of the small intensity differences between adjacent tissues, surgeons cannot effectively isolate such structures. To address the shortcomings of the traditional photorealistic volume rendering algorithms, we propose a new non-photorealistic process for high-quality volume visualization of segmented data.

Of the NPVR process, we take three steps, which is inspired from histogram equalization algorithm in image process.

1) Firstly, the average color of every structure is calculated. Then if non-RGB space, color space transform is needed at first.

2) Secondly, color histogram equalization is done in color space including RGB, YUV or HSI. The cumulative histogram of each component of color space is computed and then the histogram equalization is done. For YUV, only Y is considered. For HSI, only I is considered. And for RGB, all components are considered.

3) Finally, the color value needs to be transformed to the original RGB space for visualization.

In order to verify our idea, we use thorax data set from VHP female data set and internal structures are marked by interactive segmentation. Average color in segment is used for the whole segment. Figure 3 gives the result for color stretch in different color space. The result shows the color difference is enlarged obviously through histogram equalization.

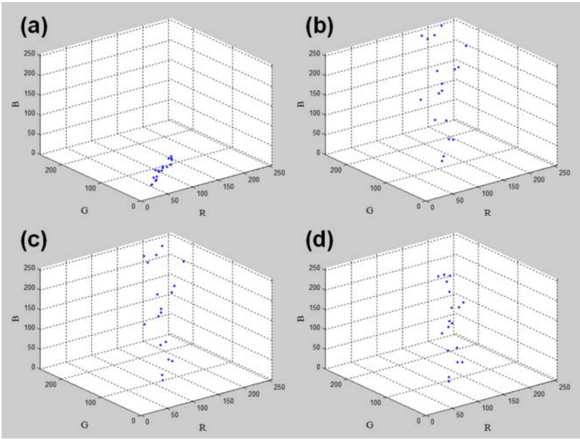

Figure 3. The result of histogram equalization in different color space: (a) Original color distribution. (b) Histogram equalizationin RGB space. (c) Histogram equalizationin YUV space. (d) Histogram equalization in HSI space.

5. Two-level volume rendering

Highlight specific object and view internal structure is one of the most important goals in volume rendering. Here, we used the two-level volume rendering technique, which is capable of integrating indirect and direct volume rendering techniques.

As shown in Figure 4, the basic idea of two-level volume rendering is that global and local rendering are considered in different phases. In this paper, we use direct surface rendering for interested object and direct volume rendering for other objects.

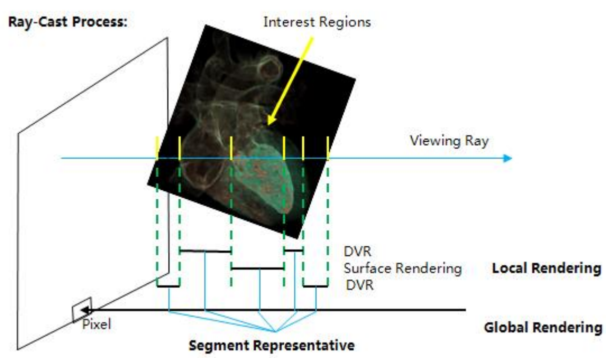

Figure 4. Two-level volume rendering

6. Results and discussions

In this section, thorax data set from the female data set of Visible Human Project is used for test. Each image has a 2048×1216 pixel resolution with physical resolution 0.33×0.33 mm. Interactive segmentation is used to mark the internal structures of heart.

We have implemented this algorithm in our 3D volume rendering platform, using C++, OpenGL and OpenGL Shading Language (GLSL) on a hardware system equipped with Intel(R) Xeon(R) CPU E5-1620 0 @ 3.60GHz, 64.0G RAM and graphics card of NVIDIA Quadro 4000.

Figure 5 gives the result based on NPVR. In (a),(b) and (c), a uniform opacity is used for all voxels. And in (d), color distance gradient dot products (MIN) is used for opacity design.

Figure 5(a) shows the heart volume visualization based on segmentation, in which heart gets a clear boundary. But the structures inside is so fuzzy. Figures 5(b) and 5(c) give the results of NPVR based on RGB space and HSI space. We can find the internal structures are enhanced for viewing. And in Figure 5(d), NPVR is not used. Obviously, (d) is better than (a) for internal structure viewing, which shows the opacity design is effective.

In order to performance improvement, we combine NPVR and opacity design based on MIN. In Figure 6, NPVR based on HSI space and MIN for opacity design is used. We can see the performance of visualization is improved greatly. Furthermore, two-level volume rendering is adopted to enhance a specific object, which is shown in figure 7.

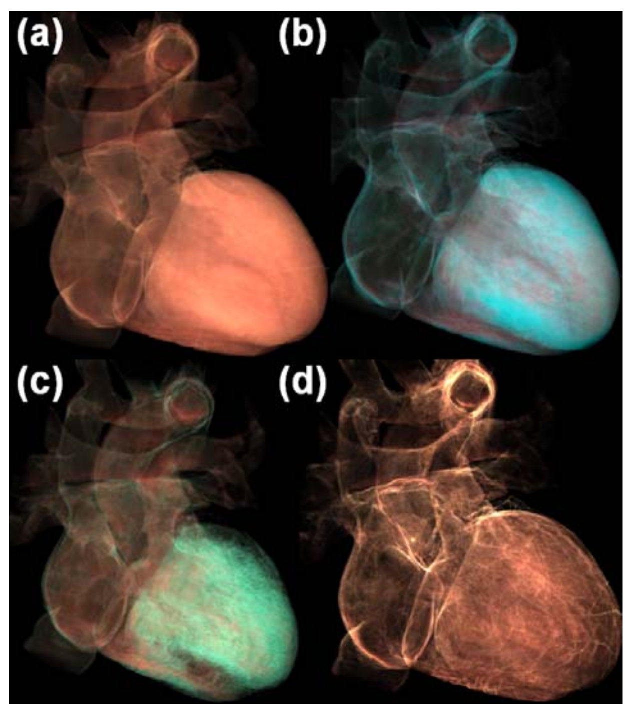

Figure 5. Visualization based on NPVR: (a) Heart volume visualization based on segmentation. (b) Based on three components of RGB NPVR process. (c) Based on I component of HSI NPVR process. (d) Based on Color Distance Gradient Dot Products (MIN).

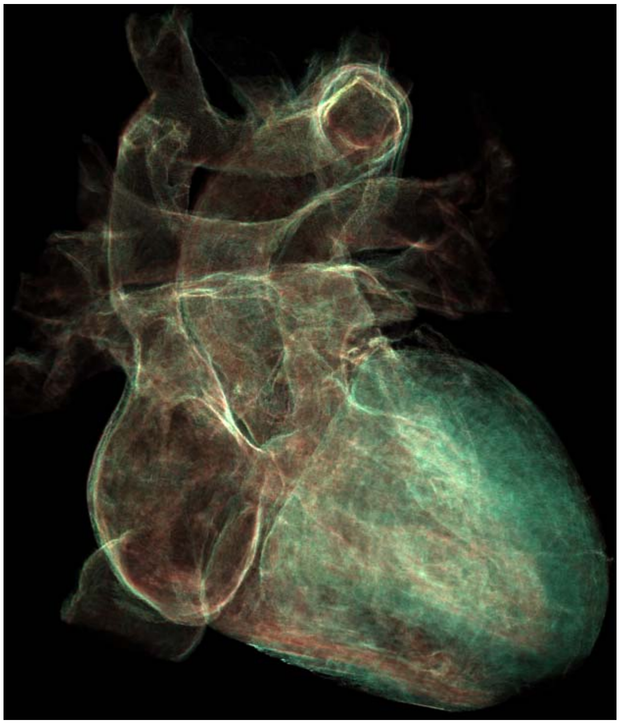

Figure 6. Heart visualization based on NPVR and MIN.

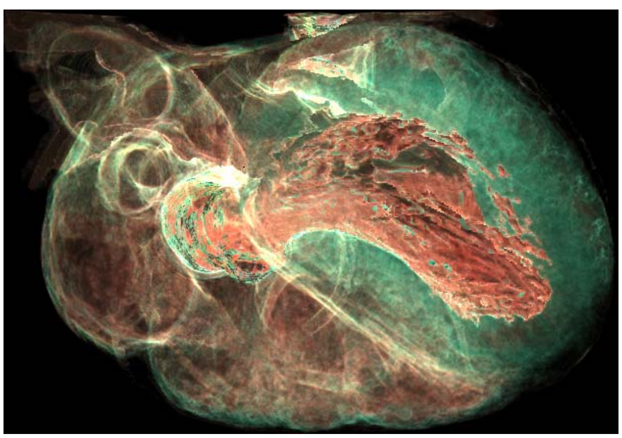

Figure 7. Heart visualization based on two-level volume rendering.

7. Conclusions

Transfer function design for volume rendering plays a crucial role for exploring directly detail information which hiding in data, visualizing subtle details, demonstrating its value in revealing structural, as well as functional abnormalities of the heart. In this paper, we strengthen color difference by usingcolor histogram equalization and use color distance gradients for opacity design. This method can enhance subtle details with only a little color change. Furthermore, we use two-level volume rendering for better performance, which proves to be effective and convenient.

Acknowledgements

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