

Visualization of Segmented Cardiac Anatomy with Accelerated Rendering Method

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Abstract

Volume rendering of 3D anatomical and medical data would be valuable in medical diagnosis and surgical planning. In this paper, we investigated the visualization of the segmented heart obtained by the cross-sectional data from the Visible Human Project, and proposed an accelerated rendering method to speed up the original ray-casting rendering method. To provide a satisfactory visualization quality on the shape and boundary of cardiac tissues, we designed the transfer function and assigned an appropriate opacity and color value for each kind of tissue. In interactive visualization, we adopt the ray casting algorithm of volume rendering and modify it to accelerate the rendering speed. We also provide the fundamental rotation and zooming operations in the visualization platform, and further implement an interface to display three regular views of the volume data. Furthermore, a clipping plane tool is provided to crop the heart at arbitrary point of view.

1. Introduction

Visualizing anatomy of the human heart is the foundation for investigating the functions of the heart at various physiological and pathological conditions. The segmented cross-sectional data from the Visible Human Project, of which each voxel is assigned a specific object category, provides the heart information with high outstanding discrimination. With the segmented heart data, visualization of segmented cardiac anatomy reproduces every detail of the original image data relevant for diagnosis [1] and is of great value in surgical planning.

Volume rendering method has been widely applied in volume visualization. Over the years many rendering algorithms have been developed to visualize volumetric data. Direct Volume Rendering (DVR) is one of the most important techniques developed to achieve direct perception of such volumetric data [2]. Compared with surface rendering methods, DVR conveys more

information, and enables the viewer to fully reveal the internal structure of 3D data [3]. For the heart visualization application, direct volume rendering techniques are crucial to gain detailed insight into the heart, in order to examine, explore and precisely pinpoint problem areas before determining final treatment strategies.

Transfer function is the predominant process in visualizing features of interest for volume rendering. The earlier transfer functions usually are one-dimensional, which used the scalar value of volume to distinguish materials. Levoy present a second dimension, jointly with the gradient magnitude, to emphasize the strong boundaries between objects [4]. Currently, curvatures [5] and special properties [6] have been used as the extra domain of transfer function to help distinguish between objects. However, with the diversity and complexity of volume data, transfer function design is still a difficult task.

Volume rendering usually suffers from the problem of enormous computation complexity and time consuming. Thus more attention has been paid in the development of fast volume rendering algorithms. Levoy [7] reduced computation time of ray casting considerably by making use of a complete octree to encode special coherence of volume data. Cohen and Sheffer proposed proximity clouds technique [8], and Sramek introduced fast ray-tracing method [9] both speed up volume rendering efficiently by preventing from resampling large unnecessary empty voxels.

In this paper, we investigated the visualization of the segmented heart obtained by the cross-sectional data from the Visible Human Project, and build a framework for exploration and visualization of the 3D segmented heart data. To provide a satisfactory visualization quality on the shape and boundary of cardiac tissues, we designed the transfer function. In interactive visualization, we adopt the ray casting algorithm of volume rendering and modify it to accelerate the rendering speed. We also provide the fundamental rotation and zooming operations in the visualization

platform, and further implement an interface to display three regular views of the volume data. Furthermore, a clipping plane tool is provided to crop the heart at arbitrary point of view.

The remainder of the paper is organized as follows. Section 2 presents the transfer function design scheme. Section 3 describes the interactive visualization scheme, including ray casting and semi-automated transfer function design. Section 4 presents an accelerated method design. Section 5 provides the experimental results and discussions. Finally, Section 6 gives our conclusion and future work.

2. Methods

2.1. Transfer function design

As an image generation and reconstruction technique, volume rendering can be applied to visualization of volume data. Since of the complexity of cardiac tissue, transfer functions are of great important to the quality of direct volume-rendered images. A transfer function assigns optical properties, such as color and opacity, to original values of the data set being visualized. With the help of transfer function, each significant tissue of heart is clearly displayed.

In this section, we designed the transfer function using the following mapping function to classify the volume data:

$$f(v) \rightarrow (Opacity, Color) \quad (1)$$

where v is the gray value of each voxel of volume data.

Since each voxel has been assigned a specific object category in the segmented cross-sectional data, the color of each voxel is determined by its gray value and the category of material it is belonged to. Thus variant tissues are classified with different colors, and voxels with variant gray values which change sharply in their neighbor area can be determined to be boundary of various materials. Considering the impact of thickness of boundary between tissues, we know the condition of thickness of boundaries qualitatively based on gray value of variant tissues and then assign those voxels which belong to the thick boundary a higher opacity. And the thinner boundary voxels are assigned a lower opacity.

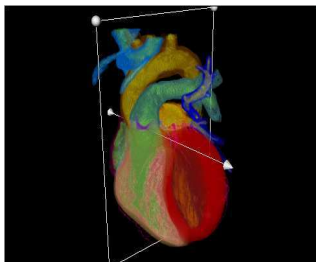


Fig. 1 Volume rendering of the segmented female heart data

From Fig. 1, it is obvious that with the help of the two dimensional transfer function described above, anatomical structure of human heart is clearly explored from the volume data.

2.2. Interactive visualization

Interaction with the rendered virtual model on a computer is beneficial for diagnosis and treatment planning support. In the interactive visualization stage, we first adopt the ray casting algorithm of volume rendering, where the result image is rendered and each significant tissue of heart is clearly displayed. This rendered virtual model is important for characterizing variant tissues and help understand the link between structure and electrophysiological function of the heart.

To inspect anatomy model of the segmented human heart from all viewing directions, we provide the fundamental rotation and zooming operations in the visualization platform. This leads to a better understanding of 3D details and the relation between the model and the original image information, as shown in Fig. 2.

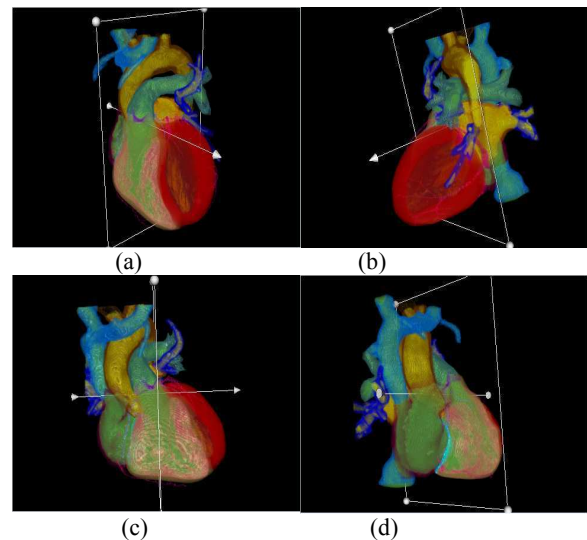


Fig. 2 Volume rendering of the segmented female heart data from all viewing directions

We further implement an interface to display the three regular views of the volume data, known as the coronal view, the sagittal view, and the transverse view. As shown in Fig. 3, colors of various tissues of heart in Fig. 2 are exactly the same with that of anatomical structures in three regular views. With these three regular projection views used in medical diagnose, different tissues are corresponded to their respective regions in slices of volume dataset.

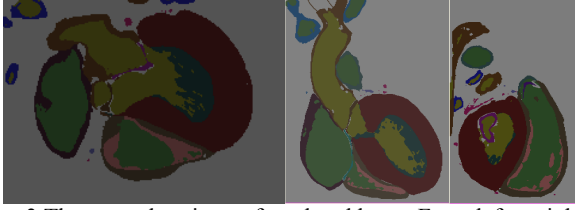


Fig. 3 Three regular views of rendered heart. From left to right: transverse view, coronal view, and sagittal view.

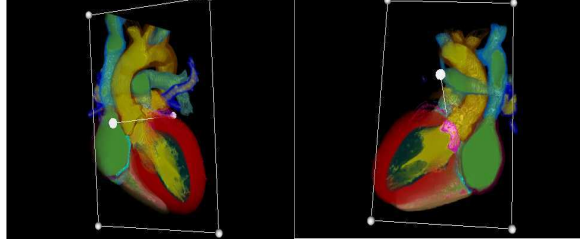


Fig. 4 Clipped cardiac anatomy by clipping plane tool

Furthermore, a clipping plane tool is provided to crop the heart at arbitrary point of view. Irregular cropped section of anatomy model is constructed. Using this method, the interior structure of the heart under this condition can be displayed. The clipping scheme includes four major steps. In the following, we briefly introduce these four steps:

- (1) Computation of the product between two vectors: we first obtain the normal vector of the clipping plane and the cast ray through volume data, and then compute the product between the two vectors which is represented as $n \cdot r$, where $n=[n_x, n_y, n_z]$ denotes the normal vector and $r=[r_x, r_y, r_z]$ denotes the cast ray.
- (2) Exploration of the relationship between the clipping plane and the cast ray: if the product is zero, this means that the plane is parallel to the cast ray. Otherwise, we recompute the cast ray vector.
- (3) Calculation of the distance: we obtain the normalized distance from start point of the cast ray to the point of intersection of clipping plane and the ray, which is defined as

$$(Ax_0 + By_0 + Cz_0 + D) / n \cdot r, \quad (2)$$

where A, B, C, and D are four parameters of the clipping plane function. And (x_0, y_0, z_0) is the coordinate of start point of cast ray.

- (4) Generation of the new cast ray vector: after obtaining the distance, coordinates of start point and end point of cast ray are recalculated. Then coordinate of the point of intersection is represented as

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} + (Ax_0 + By_0 + Cz_0 + D) / n \cdot r \quad (3)$$

If the angle between the two vectors above is less than 90° , the start point of cast ray is located at the point of intersection. Analogously, if the angle is greater than 90° , the end point is located at the point of intersection. Using coordinates of start point and end point of ray, we generate the new cast ray vector.

2.3. An accelerated rendering method

In this section, we present an accelerated rendering method to speed up the ray-casting based volume rendering. In pre-processing of segmented dataset, boundary voxels and non-boundary voxels are identified and the non-boundary voxels are labeled with a value out of the value range of segmented dataset. When cast a ray through the volume, those interior voxels of each tissue are treated together and the color and opacity value of boundary voxels of tissues are mapped from densities as in normal ray-casting algorithm. Since there are a dominant proportion of non-boundary voxels in segmented dataset, this method could alleviate the expensive computation problem of ray casting. The method is implemented by the following stages:

- (1) Compare gray value of each voxel of the volume data with the value of 27 neighbor voxels around it.
- (2) Create a list data structure which stores the label of each voxel. If gray value of the voxel is exactly the same with the value of all its 27 neighbor voxels, we mark the element in the list corresponded to the voxel "1", which means the voxel is interior of tissue. When gray value of the voxel is different from any neighbor voxel, the voxel is a boundary voxel. We mark the element in the list corresponded to the voxel "0".
- (3) View all elements in the list. When the element is labeled "1", gray value of the corresponding voxel is assigned a specific value out of the value range of segmented dataset, such as "100". While if the element is labeled "0", gray value of the corresponding voxel remains unchanged.
- (4) When a ray is casted through the volume, the opacity of interior voxels is directly assigned as "0". Otherwise, the opacity of boundary voxels is acquired using the transfer function described in Section 2.

3. Results

In this section, we use the segmented female heart extracted from the cross-sectional data from the Visible Human Project, to evaluate the performance of the proposed accelerated method. The size of data set is $469 \times 325 \times 487$. The software of the accelerated rendering method was implemented and evaluated on PC of

Core(TM)2 Quad cpu@ 2.40G, 3.25G RAM and graphics card of NVIDIA GeForce 8600GT.

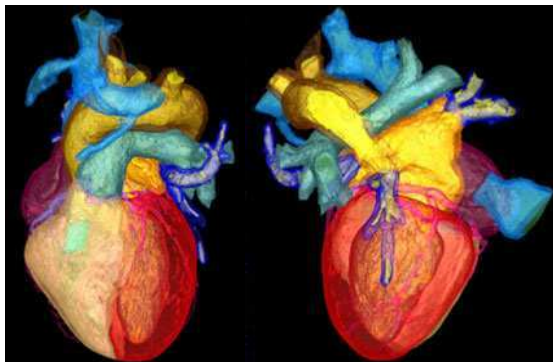


Fig. 5 Anatomical structure of human heart using the accelerated rendering method

We first evaluate the rendering quality of the accelerated rendering method. Fig. 5 shows the visualization results of the accelerated method. Compared with the results in Fig. 1, accelerated method can also achieve good rendering quality on various cardiac tissues.

Table 1 Rendering time comparison

| Volume dataset | Ray casting(s) | Accelerated rendering method (s) |
|----------------------------------|----------------|----------------------------------|
| Visible Human Heart(469×325×487) | 3.3 | 2.1 |

We further evaluate the rendering time of the accelerated method. In our experiment, we compare the rendering time of the original ray casting algorithm with the time of accelerated rendering method. Table 1 shows that the accelerated method presented in this paper can reduce time consuming.

4. Conclusions and discussion

In this paper, we investigated the visualization of the segmented heart data obtained from the cross-sectional data from the Visible Human Project, and proposed an accelerated rendering method to speed up the original ray-casting rendering method. To achieve satisfactory visualization quality on the shape and boundary of cardiac tissues, we designed the transfer function by assigning an appreciate opacity and color value for each kind of tissue. In interactive visualization, we adopt the ray casting algorithm of volume rendering to explore the cross-sectional data. We also provide the interactive rendering tool and a clipping plane tool which is provided

to crop the heart at arbitrary point of view. In accelerated rendering, we present an accelerated rendering method to speed up the original ray-casting rendering method.

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