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# Visualization using Histogram Based Transfer Functions for 3D Cardiac Volume Data Set*

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***Abstract*— A key process in the application of volume rendering is to design an appropriate transfer function according to the needs of visualization. In this paper, the design of 1D histogram based transfer function is firstly introduced to make full use of the gray levels of 3D cardiac volume data. Opacity modulation based on statistics of the specific gray level is then presented to observe the interior subtle cardiac tissues clearly. Furthermore, 2D histogram based transfer function using gray level and gradient magnitude is also proposed to enhance boundaries of cardiac tissues. Experimental results validate that our proposed transfer functions are effective and efficient in volume rendering for cardiac volume data set.**

***Index Terms*— Volume rendering, Transfer function, Histogram, Gradient magnitude**

## I. Introduction

Visualization in scientific computing is proposed in 1982 and three-dimensional data visualization has been developed quickly in recent years. Three-dimensional data visualization is divided into surface rendering and volume rendering. Surface rendering simply uses surface information to construct the 3D view and volume rendering shows the entire data field using primary data sampling skills instead of structuring the intermediate geometric primitives [1].

Transfer functions are fundamental to direct volume rendering as their role is essentially to make the data visible by assigning optical properties like color and opacity to the volume data [2]. Good transfer functions reveal the important structures in the data without obscuring them with unimportant regions.

Transfer functions have generally been limited to one-dimensional domains, meaning that the scalar data value has been the only variable to which opacity and color are assigned. There are features of interest in volume data that are difficult to extract and visualize with one dimensional transfer function. Many medical data sets created from CT or MRI scans contain a complex combination of boundaries between multiple materials. This situation is problematic for 1D transfer functions because of the overlap between data value intervals spanned by the different boundaries [3].

Heart is one of the most important organs of the human being. However, coronary disease has become one of the leading causes of death [4]. Therefore, visualization of 3D cardiac volume data set has been developed quickly in recent years. An advanced visualization method for high-resolution MRI data was proposed by Goodyer et al. [5]. A heart simulation platform which demonstrated the cells, tissues and organs of heart was developed by Hurmusiadis [6]. An accelerated visualization algorithm which was tested on the sheep heart data set and the visible human cardiac data set was designed by Yang et al. [7]. Effective transfer function for interactive visualization and multivariate volume data was proposed by Wang et al. [8]. Real-time interactive heart illustration platform via hardware accelerated rendering was developed by Zhang et al. [9]. Strategy of statistics-based visualization for segmented 3D cardiac volume data set was proposed by Gai et al. [10].

In this paper, statistics in 1D histogram of cardiac volume data is used in our experiment to make full use of the gray levels of cardiac volume data and to modulate the opacity of cardiac tissues. 2D histogram based transfer function using gray level and gradient magnitude is proposed to get clear contour of heart and to enhance boundaries of cardiac tissues.

The rest of this paper is organized as follows. Section 2 introduces 1D histogram based transfer function and 2D histogram based transfer function. Section 3 presents experimental results using the proposed transfer functions. Section 4 concludes the whole paper.

## II. DESIGN OF TRANSFER FUNCTIONS

Transfer function, which converts data values from 3D data field to optical parameters, is a key process for volume rendering [11]. By selecting appropriate data and optical property and establishing the relationship between them according to the needs of visualization, we can design an optimal transfer function for volume rending.

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### A. 1D Histogram Based Transfer Function

Transfer functions emphasize regions in the volume by assigning color and opacity to data values. It is difficult to design transfer functions because of the iterative procedure that requires significant insight into the underlying data set.

Histograms are useful in analyzing the distribution of data value, indicating which ranges of values are important. 1D histogram of cardiac volume data set is shown in Fig.1, where the horizontal axis corresponds to gray level and the vertical axis corresponds to the number of voxels of each gray level in the data set. 1D histogram of cardiac volume data set shows the distribution of gray levels in the data set, illustrating the gray levels of cardiac tissues are in the range of [30,70].

Gray level is used as index to fetch the optical property of each voxel in cardiac volume data set during the rendering process. Equation (1) describes the mapping rule.

$$C_{rgba} = F(g) \tag{1}$$

where $C_{rgba}$ is the optical property, g is the gray level and F is the mapping function which can be implemented in the lookup table.

Gray levels of cardiac tissues are distinctive from each other, so we can determine the color and opacity of different cardiac tissues according to the gray level of each cardiac tissue. Different colors are employed to represent different cardiac tissues according to the relative location of tissues in the cardiac anatomical model. In order to make the interior tissues visible, the opacity of interior tissues is larger than that of exterior tissues according to the spatial distribution of cardiac tissues. The transfer function which is implemented in the lookup table is shown in Fig.2.

Many heart diseases can be diagnosed according to the occlusion of the mitral valve which is between the left atrium and the left ventricle. Although different cardiac tissues can be distinguished easily using 1D histogram based transfer function, the interior subtle cardiac tissues like the mitral

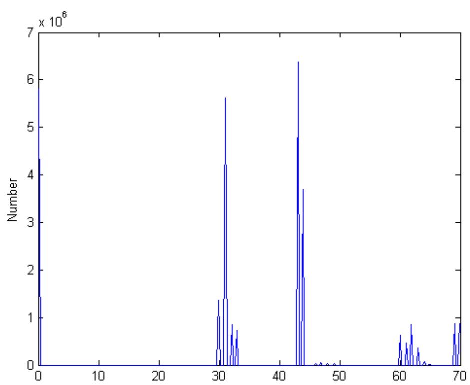
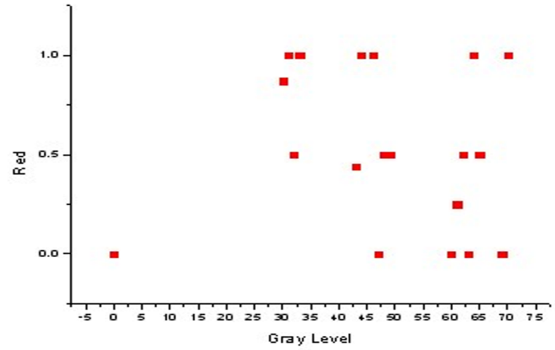
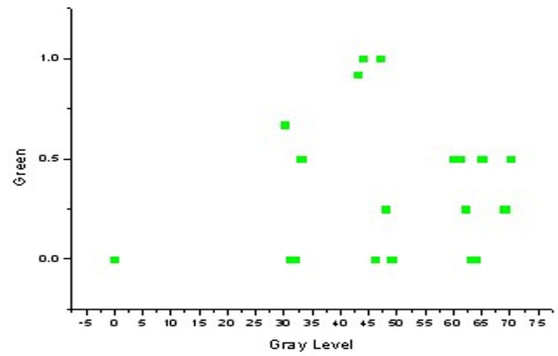


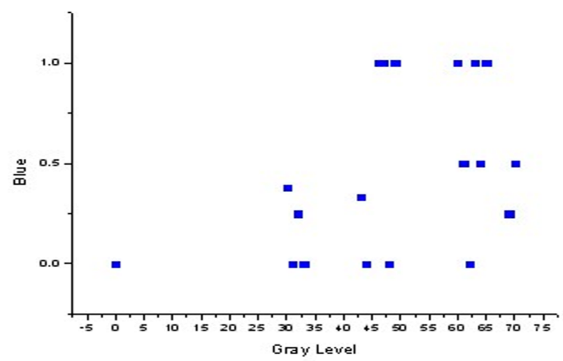

Fig. 1. 1D histogram of cardiac volume data set.



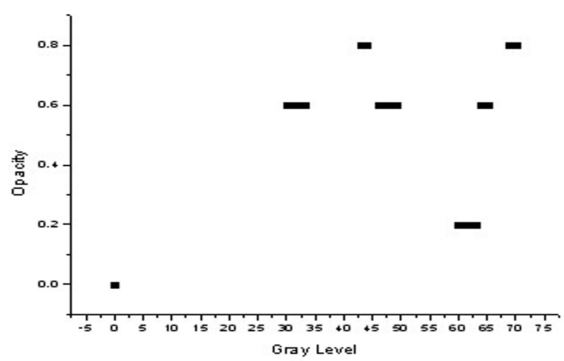

(a)




(b)




(c)




(d)

Fig. 2. 1D histogram based transfer function: (a) red value of each gray level. (b) green value of each gray level. (c) blue value of each gray level. (d) opacity of each gray level.

valve still can't be observed due to the block of exterior tissues. Opacity modulation is proposed to solve the problem.

In order to observe the interior subtle tissues, we can increase the opacity of the interior subtle cardiac tissues and decrease the opacity of exterior cardiac tissues to reduce the impact of the block of exterior tissues. As the gray levels of cardiac tissues are distinctive from each other, the opacity of cardiac tissues can be modulated according to statistics of the special gray level.

The opacity of cardiac tissues is modulated as follow:

$$\alpha_s = \alpha_o + N - \lg(num(x))/k \tag{2}$$

where $\alpha_s$ is the shaded opacity, $\alpha_o$ is the original opacity, $N$ and $k$ are constant values, $num(x)$ is the number of voxels with the gray value x in cardiac volume data set. $N$ is assigned $4/k$ according to statistics of each tissue in cardiac volume data set in our experiment.

### *B. 2D Histogram Based Transfer Function*

Boundaries of cardiac tissues in the rendering result using 1D histogram based transfer function are not obvious. Gradient characterizes the rate of change of values in the adjacent voxels and can be used to enhance boundaries of cardiac tissues.

Central differences are used to obtain the gradient vector at each voxel. 2D histogram based transfer function is then designed to enhance boundaries of cardiac tissues by using gray level and gradient magnitude in our experiment. Gradient computation using central differences is as follow:

$$\begin{aligned}
&P(.) = P(x,y,z)\\
&G\left(P(.)\right) = \sqrt{G_x\left(P(.)\right)^2 + G_y\left(P(.)\right)^2 + G_z\left(P(.)\right)^2}\\
&G_x\left(P(.)\right) = \frac{\mathrm{V}\left(P\left(x+h,y,z\right)\right) - \mathrm{V}\left(P\left(x-h,y,z\right)\right)}{2h}\\
&G_y\left(P(.)\right) = \frac{\mathrm{V}\left(P\left(x,y+h,z\right)\right) - \mathrm{V}\left(P\left(x,y-h,z\right)\right)}{2h}\\
&G_z\left(P(.)\right) = \frac{\mathrm{V}\left(P\left(x,y,z+h\right)\right) - \mathrm{V}\left(P\left(x,y,z-h\right)\right)}{2h}
\end{aligned} \tag{3}$$

where $G(P(x,y,z))$ is the gradient at point P, $G_x(P(x,y,z))$ is x axis gradient at point P, $G_y(P(x,y,z))$ is y axis gradient at point P, $G_z(P(x,y,z))$ is z axis gradient at point P and h is the distance between the voxels along a coordinate axis.

To make the boundaries of cardiac tissues obvious, 2D histogram based transfer function using gray level and gradient magnitude is proposed. On the basis of 1D histogram based transfer function, the opacity of the boundaries is modulated according to gradient magnitude of each voxel in cardiac volume data set. Equation (4) is used in our experiment.

$$\alpha_s = \alpha_o + \beta\frac{G_p + N_1}{G_{\max} + N_2} \tag{4}$$

where $\alpha_s$ is the shaded opacity, $\alpha_o$ is the original opacity, $\beta$ is a constant value, $N_1$ and $N_2$ are nonnegative numbers, $G_p$ is the gradient magnitude at point P, $G_{\max}$ is the maximum gradient magnitude of all voxels in cardiac volume data set. $(G_p + N_1)/(G_{\max} + N_2)$ is in the range of [0, 0.1] after $N_1$ is assigned 0 and $N_2$ is assigned $9 \times G_{\max}$ according to the needs of visualization for cardiac volume data set. $\beta$ is the only parameter that is used to modulate the opacity of boundaries of cardiac tissues. 2D histogram based transfer function is shown in Fig.3.

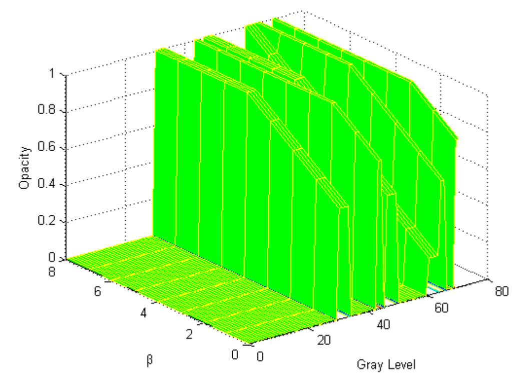


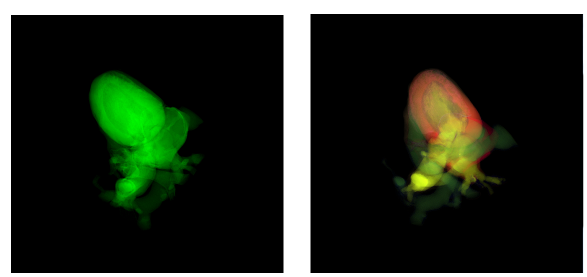

Fig. 3. 2D histogram based transfer function.

## III. EXPERIMENTAL RESULTS AND DISCUSSION

### *A. Results using 1D Histogram Based Transfer Function*

Comparison between the rendering result using a general transfer function and that using 1D histogram based transfer function is shown in Fig.4. Different cardiac tissues are represented by different colors in Fig.4(b). The rendering result using 1D histogram based transfer function makes cardiac tissues easier to be distinguished than that using a general transfer function.

The rendering results using opacity modulation are shown in Fig.5. The rendering result contains much information that can be obtained through reasonable parameter adjustment of k. The interior subtle cardiac tissues like mitral valves can be



(a) (b)

Fig. 4. Comparison between the rendering result using a general transfer function and that using 1D histogram based transfer function: (a) the rendering result using a general transfer function. (b) the rendering result using 1D histogram based transfer function.

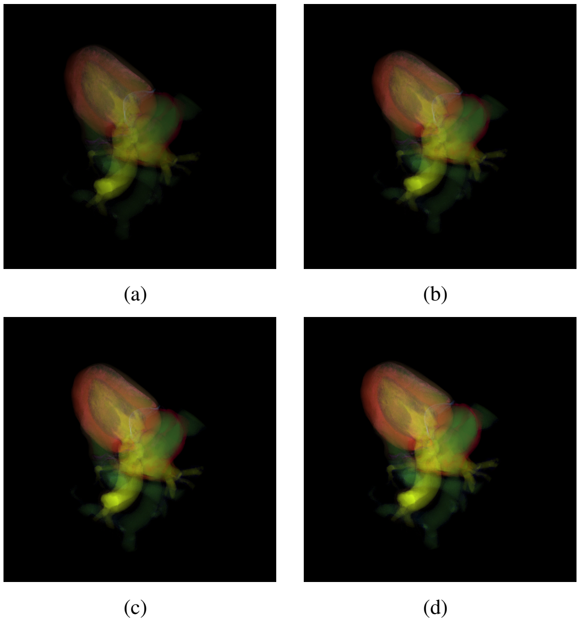



Fig. 5. The rendering results using opacity modulation: (a)k=15. (b)k=20. (c)k=25. (d)k=30.

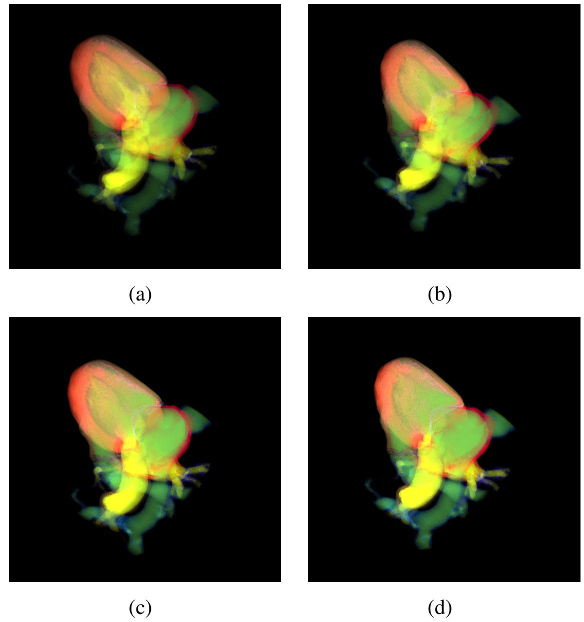



Fig. 6. The rendering results using 2D histogram based transfer function: (a)$\beta$ =1. (b)$\beta$ =2. (c)$\beta$=3. (d)$\beta$ =4.

observed by modulating opacity of cardiac tissues according to (2). It is validated that our approach is successful in the opacity modulation.

### *B. Results using 2D Histogram Based Transfer Function*

The rendering results using 2D histogram based transfer function are shown in Fig.6. Boundaries of cardiac tissues and the contour of the heart are obvious by using 2D histogram based transfer function. The outer wall of cardiovascular is also obvious through the parameter adjustment of $\beta$. When $\beta$ increases, the rendering results get a clear contour of the heart and obvious boundaries of cardiac tissues. Results validate that the proposed method is successful in boundary enhancement.

## IV. CONCLUSION

In this paper, histogram based transfer functions are addressed. Statistics in 1D histogram of cardiac volume data set is used to make full use of the gray levels of cardiac volume data and to modulate the opacity of cardiac tissues. 2D histogram based transfer function using gray level and gradient magnitude is implemented to get clear contour of heart and to enhance boundaries of cardiac tissues. Using 3D cardiac volume data set, experimental results indicate that our proposed methods can provide high quality rendering results. Besides, the proposed transfer functions are also expected to be applicable to other medical data sets and to be incorporated into the existing volume rendering platform.

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