

# Gaussian Function in Brain Vessel Volume Rendering Based on Point of Interest

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**Abstract-** We propose a volume rendering method that is capable of highlighting the region of interest and preserving contextual information so as to assist in accurate location and diagnosis on medical imaging data. The region of interest was marked, followed by recording spatial location of the first contour surface along the ray direction. According to the distance between sampling point and the point of interest, and the angle of ray and the connecting line of sampling point and point of interest, attenuation function was created by using Gauss function, which acted on opacity transfer function to control ray synthesis. The experimental result from head CT scan indicates the proposed method can highlight region of interest under the premise of preserving a clear tissue contour.

**Keywords-** Volume Rendering; Iso-surface; Gaussian Function; Opacity

## I. INTRODUCTION

In recent years, volume rendering techniques have been widely used in the medical field by radiologists to analyze and locate regions of interest in volume rendering image to make accurate diagnosis and radiotherapy planning. Volume rendering effect has a great influence on a doctor's decision. Ray casting algorithm, one of the commonly used methods of direct volume rendering, can meet requirements for imaging reconstruction and has been widely applied in the medical field [1]. However, the algorithm results in overlay and occluding regions between the reconstructed tissues, which adversely affect accurate locating of region of interest and the diagnosis.

In order to solve the aforementioned problem, the commonly adopted solution is cutaway and optimization of transfer function to highlight the region of interest. Cutaway technology can remove the occluding tissues completely, directly displaying the tissue of interest, but cutaway is the unselective removal of occluding region which leads to loss of contextual information, and even removal of part of tissues of interest [2, 3]. The role of the transfer function is to obtain corresponding color and opacity values by image intensity information, reducing opacity of region of less importance and increasing opacity of the region of interest to achieve perceptual salience. But finding a proper transfer function is complex and time-consuming even for specialists. Stefan Bruckner introduced the method of maximum intensity difference accumulation (MIDA), to combine the DVR and MIP advantages to reduce the design complexity of transfer function, but in the accumulation process some local features will miss [4]. The multi-dimensional transfer function design can make the region of interest more salient by enhancing boundaries contrast between various tissue types, and it can effectively distinguish different tissues but with complex user interaction [5].

In order to integrate the advantages of the transfer function and cutaway effect, Stefan Bruckner proposed the context-preserving volume rendering (CP-VR) model [6]. The CP-VR model constructed opacity attenuation function by using gradient magnitude. With illumination intensity and the distance between sampling point and the viewpoint as opacity attenuation function parameters, the structure can be preserved and the virtual cutaway effect can be achieved. The improved CP-VR model achieves a good visual effect [7]. The context-preserving method based on interactive hotspots suggested by Jens Krüger et al. is followed, which uses the opacity function and proposes special synthesis of the region of interest, to facilitate users to observe complex data [8]. Michael Burns et al. proposed that the cutaway is done to achieve a visual effect after information of varying importance is introduced to transfer function to make a focus region more salient [9]. However, importance classification is subjective since it involves users' participation.

One of the purposes of the transfer function is to achieve a good visual effect with less users' interaction, but the rendering results of the transfer function without users' participation cannot help facilitate user's perception. Doctors observe three-dimensional objects, very often with certain focus. These focal points tend to be occluded by such body tissues as bone, especially of the skull on the cover of cerebrovascular. Good results cannot be obtained only through regulating the transfer function. Cutaway requires more users' involvement and produces an incomplete impression. Rezk-Salama proposed opacity peeling drawing algorithm, simply by setting the opacity threshold hierarchical rendering volume data to solve the occlusion problem, but the context information is incompletely kept [10]. The key point of transfer function should be highlighting tissues which doctors emphasize, preserving their context, and reducing user's involvement. The method of optimizing transfer function achieves perceptual salience by increasing contrast between various tissue types and enhancing visual distinction between tissues of interest and their peripheral ones. It is more flexible than cutaway techniques and requires less human-computer interaction.

This study puts forward a novel method to optimize transfer function [11]. Creating a transfer function based on Gauss

function by using geometric data related to the point of interest, we propose a Gauss volume rendering method based on points of interest, which can effectively highlight regions which doctors deem important and preserve contextual information.

## II. METHOD

### A. Ray Casting Algorithm

Three-dimensional continuous data field is expressed by  $f(P_n)$ , with  $P_n$  representing the coordinates of a sample point in the three-dimensional data field. At the sampling point  $P_i$ , gray value and gradient magnitude are  $f_{P_i}$  and  $g_{P_i} = \nabla f(P_i)$  respectively.  $\|g_{P_i}\|_{[0..1]}$  is the modulus of the normalized gradient.

In the process of ray casting algorithm, we use discrete approximation points along the ray direction to synthesize the optical properties of the sampling point from front to back and obtain color values and opacity values of this viewpoint on the imaging plane. The specific synthetic formula after discretization is as follows:

$$\alpha_i = \alpha_{i-1} + \alpha(P_i) \cdot (1 - \alpha_{i-1}) \quad (1)$$

$$c_i = c_{i-1} + c(P_i) \cdot \alpha(P_i) \cdot (1 - \alpha_{i-1}) \quad (2)$$

$$\alpha(P_i) = \alpha_{tf}(f_{P_i}) \quad (3)$$

$$c(P_i) = c_{tf}(f_{P_i}) \cdot L(P_i) \quad (4)$$

Where  $\alpha(P_i)$  stands for opacity value and  $c(P_i)$  color value of the current sample point;  $\alpha_{i-1}$  is accumulated opacity value and  $c_{i-1}$  accumulated color values before viewpoint comes into the current sampling point;  $\alpha_i$  and  $c_i$  stand for accumulated opacity value and color values respectively after viewpoint comes into the current sampling point.  $\alpha_{tf}()$  and  $c_{tf}()$  are opacity degree and color transfer function.  $L(P_i)$  is illumination brightness of the current sampling point. The Phong-Blinn model is employed commonly.

$$L(P_i) = k_a + k_d \cdot \|\hat{L} \cdot \hat{g}_{P_i}\| + k_e \cdot (\|\hat{H} \cdot \hat{g}(P_i)\|)^m \quad (5)$$

We denote coefficients of ambient light, diffuse reflection light, the specular reflection light as  $k_a$ ,  $k_d$  and  $k_e$  respectively  $m$  stands for specular reflection light convergence index.  $\hat{L}$  is the incident direction vector, and  $\hat{H}$  is the half-angle vector. Usually in direct volume rendering the opacity value of the sampling point is related to the value at the sampling point and opacity transfer function. In order to produce a sharp boundary between different tissue types, an effective method is to introduce gradient operator into the opacity, as follows:

$$\alpha(P_i) = \alpha_{tf}(f_{P_i}) \cdot \|g_{P_i}\|_{[0..1]} \quad (6)$$

### B. Gaussian Function Volume Rendering Based on Point of Interest

Fig. 1 is the model sketch map, where black point is the current sample point  $P_i$  whose space coordinates is  $s_i$ . Hollow circle represents the spatial centre of region of interest named as  $c$ , and the distance between  $C$  point and the current sampling point is represented as  $d$ .  $\theta$  is the angle between ray and the vector from sampling point to the centre of important region. Using the aforementioned geometry related to centre of region of interest, attenuation function can be created based on standard Gaussian function. The method is to use  $d$  as input  $x$  in Gaussian function, and use  $k \cdot (1 - \cos(\theta))$  as the variance of the Gaussian function. The attenuation function is as follows:

$$m(P_i) = \frac{1}{\sqrt{2\pi} \cdot \sigma} e^{-\frac{x^2}{2\sigma^2}} \quad (7)$$

$$\sigma = k \cdot (1 - \cos(\theta)) \quad (8)$$

$$x = d = \text{dis}(s_i - c) \quad (9)$$

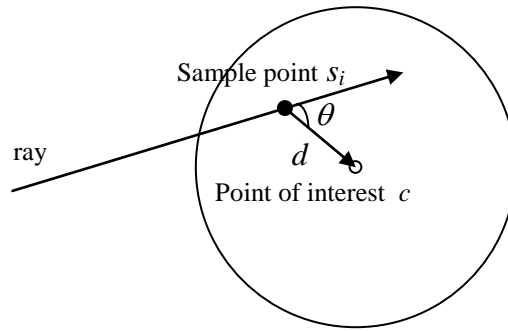


Fig. 1 Model sketch map

Where  $k$  is adjusting parameter, which is related to the size of perspective region, Users can adjust it to obtain various imaging effects. As Gaussian function input, parameter  $d$ , which is the distance between current sampling point and point of importance, is adjusted to preserve the tissues adjacent to the point of importance and to properly attenuate the tissues far from the important point. By this way the important region can be accentuated and less important region can be suppressed. But we can not fade out bone occluding the head relying solely on the distance parameter. The adoption of a single distance parameter may result in excessive suppression of details in remote tissues. This problem can be solved by introducing parameter  $\theta$ , the angle between ray and connecting line from sample point to point of interest. In the condition of  $\theta > 0$ , a smaller value of  $\theta$  means that the specific tissue obscures more significantly the region of interest; and a bigger angle indicates less association between sampling point and region of interest, which needn't be attenuated. The bigger  $\delta$  means more smooth Gaussian function and less contribution to attenuation. After these parameters are introduced into a Gaussian function, the final ray synthesis formula is listed as follows:

$$\alpha_i = \alpha_{i-1} + \alpha(P_i) \cdot (1 - \alpha_{i-1}) \quad (10)$$

$$c_i = c_{i-1} + c(P_i) \cdot \alpha(P_i) \cdot (1 - \alpha_{i-1}) \quad (11)$$

$$\alpha(P_i) = \alpha_{ff}(f_{P_i}) \cdot m(P_i) \quad (12)$$

$$c(P_i) = c_{ff}(f_{P_i}) \cdot L(P_i) \quad (13)$$

### C. Modal Analysis

Larger  $\delta$  indicates steeper function curve and smaller  $\delta$  indicates smoother one for the normal Gaussian function, and the output value is determined by the distance between sampling point and center point of important region. Fig. 2 shows Gaussian functions with various variances.

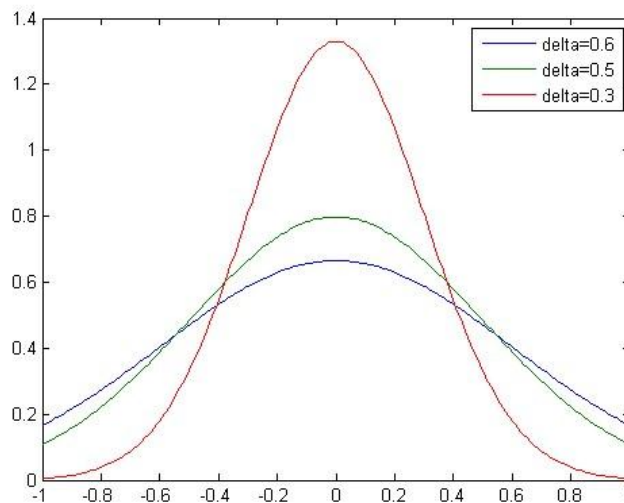


Fig. 2 Gaussian function contrast with various variances

#### 1) Input Parameter:

Formula 3 gives Gaussian function the input parameter  $x$ , which stands for the distance from current sample point to center point of important region. The distance parameter has little influence on the output of the formula (7) with larger  $\delta$ . When  $\delta$  is

small, the distance parameter affects the output of the formula greatly. It can be understood as the distances between ray and both central point of important region and the current sample point are very small, the formula (7) image will become very steep, similar to red Gaussian function curve in Fig. 2. At this time the formula (7) is very sensitive to changes in  $x$  value.

### 2) Variance Parameter:

For the same input parameter  $x$ , in all the concentric circles, which center on the central point of region of interest, Gaussian function curve will become steeper, corresponding to the red curve in Fig. 2 with smaller angle  $\theta$ , and thus different attenuation for sampling points in concentric circles is applied.

### 3) Adjusting Parameters:

The main role of adjusting parameter  $k$  is to control the size of the perspective region, and the adjustment is linear increment or decrement. Users can quickly obtain desirable imaging results which enable users to make convenient observation of area of interest.

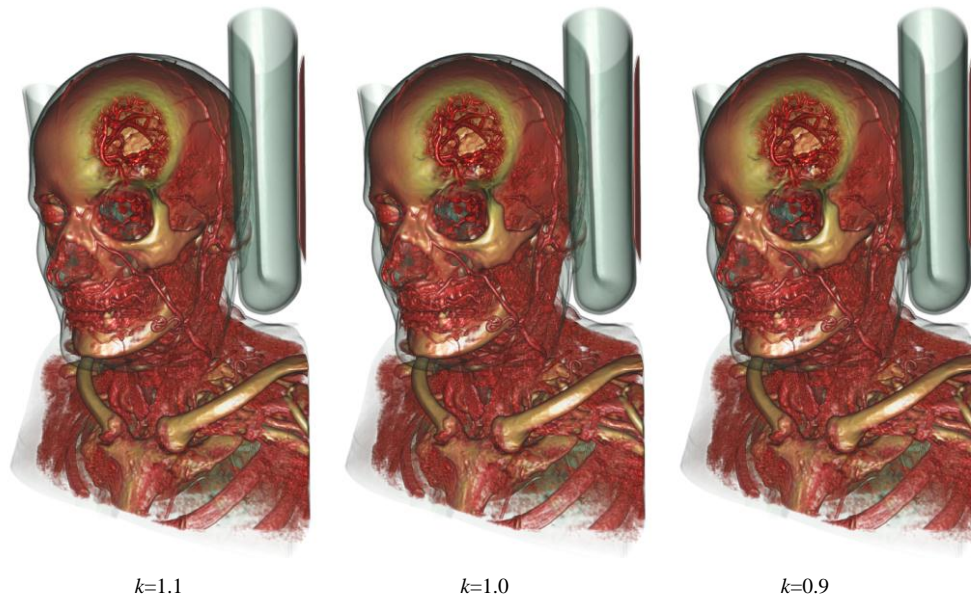
## III. EXPERIMENT AND DISCUSSION

To validate the algorithm, we used the computer configuration as follows: CPU 3.00GHz Intel (R) Core 2, Memory 1GB DDR2 and graphics card Quadro FX 1700. Programming environment is Windows XP and Visual Studio C++ .NET 2008.

Fig. 3 is experimental effect diagram, the data are results of skull vessels after contrast, doctors focusing on vessels. Fig. 3 illustrates the visual effect of vessels in the skull at different  $k$  values with default isosurface gradation value of 0.01. With larger  $k$ , there is smaller perspective area in bones occluding the important region. With the parameter  $k$  ever decreasing, the bone in the skull will be faded away gradually. The user will therefore get a broader view span and a clearer view of the tissues in region deemed important.

Fig. 4 shows contrasting visual effect using two different methods with the same transfer function. Fig. 4 (a) shows the cutaway effect using the improved CP-VR model. Cutaway method requires a certain understanding of the cutaway structure. Users are supposed to locate the cutaway parts to be prepared to do cutaway. Fig. 4 (b) is the imaging of the proposed method. The user need only select a point in the region deemed important, without being familiar with its structure, and they can fade away the skull bones blocking our view of the important region (vessels within the skull).

This method can help us obscure skull bones which block our view of vessels, while decreasing the degree of fading away of the vessels within the skull to ensure a visual effect with completeness and a high clarity. The proposed method better preserves the contextual information of the region of interest as well as overall spatial structure information of the head. Another advantage of the proposed method is that perspective region can rotate with data rotation, because the perspective region is determined by viewpoint as well as sampling points and the rotation does not need parameter re-adjusting. The biggest advantage of this method is that after data are rotated we do not have to re-build a cutaway plane or curved plane to do the cutaway, thus reducing human-computer interaction, and speeding up users' information access speed.



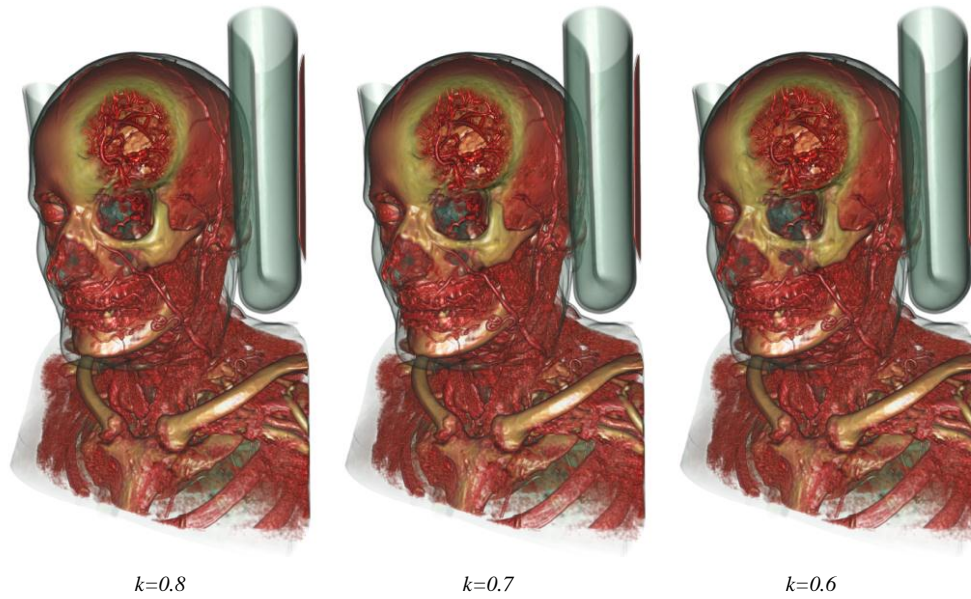


Fig. 3 Rendering of the head with various parameters

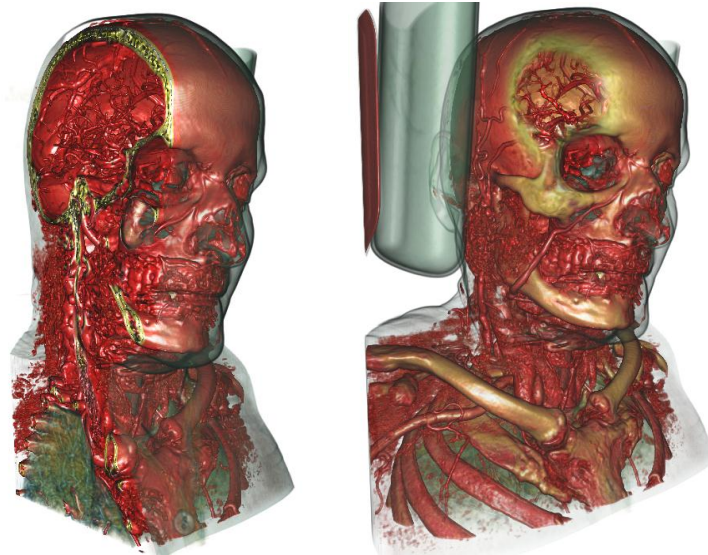


Fig. 4 The effects after CT angiography using two methods, (a) CP-VR model sectioning; (b) The proposed method

#### IV. CONCLUSIONS

The region of interest is obscured, so it is difficult to obtain a desired visual effect only by regulating transfer function; cutaway technique needs too much additional knowledge and user's interaction. Motivated by the abovementioned problems, this paper put forward Gaussian volume rendering method based on a point of interest. Users first select a point in the region deemed important to construct a geometry model, which needs the following parameters: Connected line between sampling point and point of interest, the direction of ray, and spatial information between boundaries in volume. Based on these data we create the Gaussian function, and modify the opacity of the current sampling point, thereby preserving more detailed information within the tissue to provide a more desirable imaging effect.

In particular, for the head data after CT contrast, because after CT contrast gray values in vessels are very similar to that in bones, it is difficult to distinguish them visually simply by adjusting the transfer function. Doctors very often focus on vessels and do CT angiography. The proposed method can let bones fade out and produce a visual distinction between vessels in the skull and bone. In future experiments, the focus will be the application of this method in different tissue types and the non-contrasted data to make this method more feasible. In addition, this study did not adopt CUDA to accelerate ray casting algorithm, whose accelerating effect for large data computing is very significant, our follow-up studies will include CUDA to achieve better display and interaction.

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