A Blinn-Phong Light Enhancement Algorithm Based on the Gradient of Voxel

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Abstract. Although the classical Blinn-Phong illumination model in direct volume rendering has a good display effect on the boundary of volume data field. However, the setting of the parameters fails to provide information about the valid combination data, thus limiting the performance of the model. To solve this problem, this paper proposes a Blinn-Phong light enhancement algorithm based on the gradient of voxel. Firstly, the gradient modulus of voxel gray value was calculated by using the central difference method. Then, the gradient modulus is linearly mapped to the mirror exponent and the opacity coefficient. Then calculate the ambient light, diffuse light, specular reflected light and integrated light intensity according to Blinn-Phong illumination model. Finally, the composite light intensity is multiplied by the opacity coefficient to get the final color value. This algorithm combines the gradient information of the gray value of the volume data and uses the gradient modulus to distinguish the boundary and the interior of the substance. On the basis of Blinn-Phong illumination model, different high-light and opacity illumination effects are assigned to different the gradient of voxel. The algorithm can enhance the contrast of the image, further highlight the area of user interest, and obtain more real volume rendering effect. The algorithm is applicable to the volume rendering system of objects with smooth surface and complex internal structure.

Keywords: Direct volume rendering, gradient, ROI, Blinn-Phong illumination model.

1. Introduction

Direct Volume Rendering is an important method of volume data visualization, which was developed with the maturity of medical imaging technology in the 1970s. Direct body rendering first requires classification of volume data, then different optical features such as colors and opacity values are assigned to different volume data according to Transfer Function, and then the final imaging effect is determined according to the relative position of viewpoints and volume data in space. The core of direct volume rendering is to highlight the Region of Interest through transfer function design or illumination design. Different users have different areas of interest. In general, the locations where the voxel grayscale varies greatly often contain more information, so it is more likely to be the areas of interest for users

In direct volume rendering, lighting design can effectively reflect the spatial relationship of the feature area in the volume data, as well as the surface shading of the feature area, and enhance the shape perception of the feature area. The Phong illumination model[1] is the first influential empirical illumination model proposed in real graphics. Levoy first applied the Phong illumination model to volume rendering[2]. The Phong illumination model belongs to the empirical model. Based on the pure diffuse reflection model, the effect of mirror reflection is considered. The model only considers the object's specular reflection of directional light, and does not consider the specular reflection of ambient light (considering that only diffuse reflection of ambient light occurs). Blinn-phong illumination model[3]] improves the vector operation in the phong illumination model. This makes computing significantly faster, and it provides softer, smoother highlights than the Phong light model. Although the Phong illumination model can have a good drawing effect on the boundary of the body data field, But you can't get the same results in a homogeneous area. In response to this problem, Kniss et al.[4] proposed to quantify the surface in 2002. Interpolation was performed between the faces with and without light. In 2003, Weiskopf et al.[5] solved the problem of finding the normal vector of the illumination model by replacing the normal vector of the current isosurface with the normal vector of the adjacent isosurface. In 2004, Lum E. B. et al.[6] proposed an algorithm for fast calculation of the transfer function lookup table, which is more accurate in estimating the illumination effect of multilayer semi-transparent isosurface. In 2008, M. Hadwiger et al.[7] considered the effect of multiple scattering on illumination. In 2011, Xiang D. et al.[8] proposed a method to replace the normal vector of the equivalent surface with the normal vector of the cut surface.In 2015, C. Lee and M. D. Ercegovac[9] present an error compensated piecewise linear logarithmic arithmetic unit for Phong lighting hardware acceleration.

However, these improvements are aimed at solving the problem of drawing the Phong illumination model in homogeneous region. How to highlight the boundary area and how to combine the data information to improve the drawing effect of the interested area is still a research hotspot.

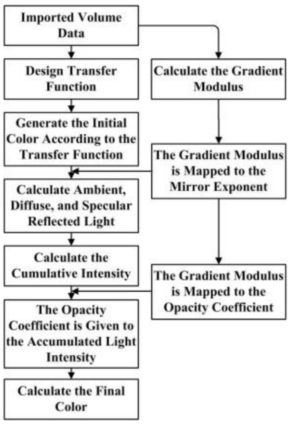


Fig. 1 Volume rendering process of Blinn-Phong light enhancement algorithm based on the gradient of voxel

In this paper, we use the gradient of voxel gray value to distinguish the characteristics of the boundary and the inner region of the substance. On the basis of Blinn-Phong illumination model, the mirror index and opacity coefficient are designed according to the gradient modulus. Different high-light effect and opacity are applied to the interior and boundary of the material, and the contrast of image is enhanced to highlight the boundary. And using the programmable pipeline technology in OpenGL, the illumination is calculated in the shader to achieve a more realistic drawing effect. The volume rendering process of Blinn-Phong light enhancement algorithm based on the gradient of voxel is shown in Fig. 1.

2. Ray Projection Algorithm

Ray Casting algorithm[10] is one of the most basic algorithms in direct volume rendering. As the algorithm needs to allocate color and opacity for each individual element, it makes full use of data information and retains more details, so the image quality is relatively high. Moreover, the light of the algorithm is independent from each other, which is very convenient for parallel processing. However, the relation between the sample points in the volume data field changes inevitably every time the line of sight is changed. This requires resampling and a large amount of calculation. Therefore, the technique of premature termination of light is generally adopted[11] to solve this problem, that is, when the cumulative opacity of a light reaches a certain threshold value, the propagation of light is terminated ahead of time and the covered voxel is abandoned.

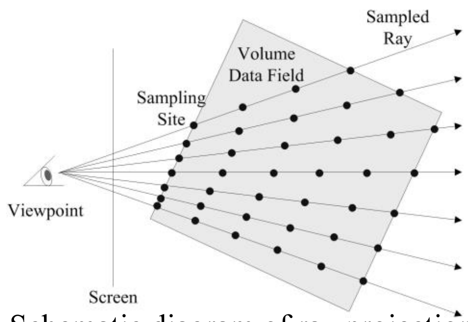


Fig. 2 Schematic diagram of ray projection algorithm

The specific steps of the algorithm are as follows:

1 Preprocess the volume data, mainly completing data format transformation, feature extraction and removal of invalid data.

2 Classify the data into several categories according to the eigenvalues of the body data and design the appropriate transfer function. Make each type of data get corresponding color value and opacity value.

3 Emit a ray through the body data field from the pixels on the screen according to the preset line of sight. Set a series of sample points with equal spacing along the direction of the ray. These new data sampling points are usually not on the original data sampling points, which are called resampling[12] points. The color and opacity values of the resample points can be approximately obtained by interpolating several raw data points closest to them.

4 Accumulate the color and opacity of each resample point in the order from front to back or from back to front along the direction of the ray. The result is the color value of the pixel. Complete the calculation of all pixels in turn to get a complete volume rendering image. Generating voxel color values and opacity according to the transfer function is only the first step in direct volume rendering, To get a more realistic ren -dering and highlight areas of interest to the user, lighting design must be added.

3. Blinn-Phong Illumination Model

Blinn-Phong illumination model is a simple and efficient local illumination model based on physical observation experience. The model assumes that the surface of the object is a non-ideal mirror reflecting body, that is not only diffuse reflection but also mirror emission. In addition, there are two kinds of light in the scene, one is ambient light and the other is directional light. The light phenomenon generated when these two kinds of light are irradiated to the surface of the object is calculated respectively. The calculation process of Blinn-Phong illumination model is as follows:

Firstly, calculate the ambient light:

$$I_{ambient} = K_d \cdot I_a \quad (1)$$

Where $I_{ambient}$ is the ambient light intensity reflected by the surface of the object, K_d is the reflection coefficient of light on the surface of the object, and I_a is the ambient light intensity.

Calculate diffuse reflectance:

$$I_{diffuse} = K_d \cdot I_d \cdot \max\left(0, dot\left(N, L\right)\right) \quad (2)$$

Where $I_{diffuse}$ is the diffuse reflection light intensity K_d is the reflection coefficient of light on the object surface, I_a is the light intensity of directional light, *N* is the vertex unit normal vector, *L* is the unit vector of incident directional light.

Calculate the reflected light of mirror:

$$I_{specular} = K_d \cdot I_d \cdot pow\left(\max\left(0, dot\left(N, H\right)\right), SP\right) \quad (3)$$

Where $I_{specular}$ is the mirror reflection light intensity, K_d is the reflection coefficient of light on the object surface, I_a is the light intensity of directional light, N is the vertex unit normal vector, H is the angular bisector unit vector of incident light unit vector and unit Angle vector, also called half Angle vector, SP is the mirror index.

Finally, calculate the cumulative intensity:

$$I_{accumulate} = I_{ambient} + I_{diffuse} + I_{specular} \quad (4)$$

Where $I_{accumulate}$ is the cumulative intensity, $I_{ambient}$ is the ambient light intensity reflected through the surface of the object, $I_{diffuse}$ is the diffuse light intensity, $I_{specular}$ $_r$ is the mirror reflection light intensity.

4. Calculation of Gradient

In body data field, the same material internal voxel with similar grey value, the boundary between different material of voxel grey value change is more intense, in the scalar field and gradient is a scalar field changes direction and the rate of change of measure, so the same material area gradient is small, the material between the boundaries of the gradient will be larger. For discrete data, the finite difference method is a fast and efficient gradient estimation method. In this paper, the most commonly used central difference method is adopted to estimate the gradient of voxel gray value.

Let $f(x_i, y_i, z_i)$ is the gray value at any point of voxel (x_i, y_i, z_i), then the gradient of this point is:

$$\nabla f(x_i, y_i, z_i) = \begin{bmatrix} f(x_{i-1}, y_i, z_i) - f(x_{i+1}, y_i, z_i) \\ f(x_i, y_{i-1}, z_i) - f(x_i, y_{i+1}, z_i) \\ f(x_i, y_i, z_{i-1}) - f(x_i, y_i, z_{i+1}) \end{bmatrix} \quad (5)$$

Further, the gradient modulus of the point can be obtained:

$$\|\nabla f_i\| = \sqrt{\left(\frac{\partial f_i}{\partial x_i}\right)^2 + \left(\frac{\partial f_i}{\partial y_i}\right)^2 + \left(\frac{\partial f_i}{\partial z_i}\right)^2} \quad (6)$$

It can be seen from (5) that the central difference method makes use of the voxel gray value of six neighborhood areas around each individual element, which is a method with high accuracy in the finite difference method.

5. Mirror Index and Opacity Coefficient Design

The Specular Power in Blinn-Phong light model can control the intensity of the reflected light. The higher the value, the more concentrated the specular light. Conversely, the smaller the value, the more scattered the specular specular light is, and the more diffuse the scattering. Because the body with strong data field gradient is more likely to be the boundary between different material, in order to make the border in brightness and internal separation of material, this article will gradient modulus value index, linear mapping to mirrors, for strong gradient modulus value voxel gives larger mirror index, at the same time as the gradient modulus value relatively small voxel gives small mirror index.

Firstly, the maximum value of voxel gray value gradient modulus in the volume data field $\|\nabla f_i\|_{max}$ is calculated. Then, all the gradient modulus values in voxel are linearly mapped to the mirror index of the point:

$$SP_i = (\|\nabla f_i\| / \|\nabla f_i\|_{max}) \bullet (SP_{max} - SP_{min}) + SP_{min} \tag{7}$$

Where SP_i is the mirror index of any point, $\|\nabla f_i\|$ the corresponding gradient modulus value of the point, $\|\nabla f_i\|_{max}$ is the maximum value of the gradient modulus, SP_{max} is the maximum value of the mirror index, SP_{min} is the minimum value of the mirror index, and the maximum minimum value of the mirror index is set by the user.

In addition to using brightness to separate the interested region and ordinary region in the volume data field, the opacity design of voxel will also be used to highlight the interested region in direct volume rendering. However, the classic Blinn-Phong model does not further study the voxel opacity generated by the transfer function. In order to solve this problem, in light design, the voxel opacity generated by the transfer function is adjusted twice. In other words, the linear mapping of gradient modulus will generate an opacity coefficient, which will give a larger opacity coefficient to the voxel at a larger gradient modulus and a smaller opacity coefficient to the voxel at a smaller gradient modulus.

Linear mapping of the gradient of voxel modulus to opacity coefficient O :

$$O_i = (\|\nabla f_i\| / \|\nabla f_i\|_{max}) \bullet (O_{max} - O_{min}) + O_{min} \tag{8}$$

Where O_i is the opacity coefficient of any point,

$\|\nabla f_i\|$ is the gradient modulus value of the point ,

$\|\nabla f_i\|_{max}$ is the maximum value of the gradient modulus,

O_{max} is the maximum value of the opacity coefficient,

O_{min} is the minimum value of the opacity coefficient, and the maximum minimum value of the opacity coefficient is set by the user.

Calculate the final color value:

$$I = I_{accumulate} \bullet O \bullet O_{original} \tag{9}$$

Where I is the final color value, $I_{accumulate}$ is the cumulative light intensity, O is the opacity coefficient derived from the linear mapping of gradient modulus, and $O_{original}$ is the opacity obtained by the transfer function.

At this point, through the design of voxel brightness and opacity in the light, different optical properties are assigned to voxel in different gradients, the image contrast is enhanced, and the boundary area of user interest is highlighted.

6. Draw Instance Analysis

The hardware environment is Intel (R) Xeon (R) e3-1225 v5 3.3 GHz processor, 64G memory, graphics card NVIDIA GeForce GTX 750 Ti, development environment is Windows 7 64-bit, VS 2008, OpenGL 3.0.

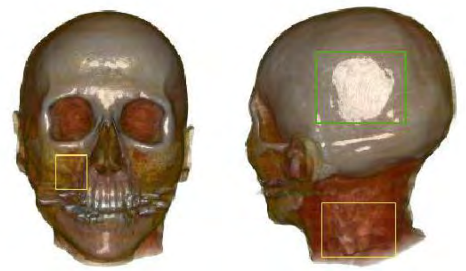
As for the volume rendering algorithm, the most widely used ray projection algorithm is adopted, and the ray premature termination technology is adopted. When the opacity value reaches 0.98, the transmission of light stops. In terms of operations, in order to improve the speed of operations, using programmable pipeline technology in OpenGL, we use Shading Language (OpenGL Shading Language) [13] to calculate illumination in Fragment Shader.

Taking the medical head data set as an example, the drawing effect is shown in Fig. 3, Fig. 4, Fig. 3 shows the rendering effect of Blinn-Phong light model, Fig. 4 shows the rendering effect of Blinn-Phong enhancement algorithm based on the gradient of voxel.

From the perspective of image brightness, compared with Fig. 3, Fig. 4 based on the algorithm in this paper has significantly higher contrast, brighter highlights and sufficient details in the dark part. From the perspective of opacity, the skeleton in Fig.3 is mostly occluded by the muscle tissue, while more internal structures can be observed in Fig.4. The upper jaw in Fig. 4 (a) and spine in Fig. 4 (b) can be clearly displayed.

(a) Front view (b) Side view

Fig. 3 Effect of the classical Blinn-Phong illumination model



(a) Front view (b) Side view

Fig. 4 Effect diagram of Blinn-Phong enhancement algorithm Based on the gradient of voxel

7. Conclusion

In this paper, a Blinn-Phong light enhancement algorithm based on the gradient of voxel is proposed to solve the problem that the classical Blinn-Phong light model in direct volume rendering cannot fully integrate data information. Firstly, the central difference method is used to calculate the voxels grey value of the gradient, the gradient modulus linear mapping of the mirror index and coefficient of opacity to here, then the environment light intensity calculated on the basis of the Blinn Phong illumination model, diffuse light intensity, mirror reflected light intensity and cumulative intensity, and finally for the cumulative intensity opacity factor is given the final color. From the drawing effect, this algorithm can effectively improve the image contrast and highlight the boundary area in both image brightness and opacity. However, the adjustment of mirror index in this algorithm can easily lead to partial overflow of highlights (as shown in Fig. 4 (b). Future work will focus on solving this problem, considering the non-linear mapping of gradient modulus to generate mirror index, and combining image optimization algorithm to further suppress the phenomenon of specular overflows.

Acknowledgments

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