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Ray-casting Algorithm Based on Adaptive Compound Interpolation

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Ray-casting Algorithm Based on Adaptive Compound Interpolation

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Abstract: The ray casting algorithm is widely used in volume rendering technology due to its mature algorithm and high imaging quality. *To solve the problems of large amount of calculation and long rendering time caused by high-quality images, the problems of re-sampling point interpolation and time-consuming synthesis in the volume rendering process based on the traditional ray casting algorithm are studied, and an improved adaptive compound interpolation ray casting algorithm is proposed. According to the set threshold range, the size of the retreating sampling step is adjusted to select the interpolation sampling point and interpolation algorithm, and the re-sampling and interpolation process are optimized.* The experimental results show that the speed of the improved method is significantly improved compared with the traditional volume rendering algorithm under the guarantee of the required image quality.

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基于自适应复合插值的光线投射算法

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摘要：光线投射算法因其算法成熟、成像质量高而被广泛应用于体绘制技术中。*为解决高质量图像带来的计算量大、绘制时间长等问题，该文在传统光线投射算法的基础上，针对体绘制过程中重采样点插值、合成耗时长问题进行研究，提出一种改进的自适应复合插值光线投射算法。依据设置的阈值范围，调整后退采样步长大小进行插值采样点以及插值算法的选取，优化重采样及插值过程。*实验结果表明，在保证所需图像质量下，此文改进方法与传统体绘制算法相比速度获得显著提升。

关键词：体绘制；光线投射算法；重采样；复合插值

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Introduction

Visualization in Scientific Computing refers to the use of computer technology to convert the generated data and calculation results into graphs and images for display and interactive processing of theories, methods, and techniques. In the field of visualization research, medical information visualization[1] uses 3D reconstruction technology to display data collected from CT, MRI, PET, etc. on the computer in an intuitive 3D image. The

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Biography: ZengYanyan(1987-), male, Gushi Henan, doctor, lecturer, research direction for the simulation method and application.

three-dimensional image has information such as depth and structure that the two-dimensional image does not have, which will greatly improve the efficiency and correctness of medical diagnosis. Researching medical information visualization has important academic significance and application value.

Three-dimensional data visualization methods are mainly divided into two categories: surface rendering[2] and volume rendering[3]. Among them, volume rendering is divided into spatial volume rendering, frequency domain volume rendering and texture volume rendering. The ray casting algorithm is a classical algorithm in the spatial volume rendering, because this algorithm has a high imaging effect, it is widely used in various medical image processing. However, because the algorithm needs to access all the voxels in the volume data, the amount of calculation is large and the rendering speed is slow, and it is far from the requirement of real-time rendering. Therefore, how to speed up the algorithm without losing image quality has become a research hot spot.

With the development of computer technology, in order to improve the rendering speed of visualization, people have proposed many volume rendering acceleration algorithms. Among them, three acceleration technologies are based on software, hardware, and parallel acceleration. The software-based algorithm accelerates the design more flexibly and has better portability, but it has a large amount of calculations and it is difficult to achieve real-time rendering requirements when the volume of data is large. In contrast, the acceleration of the latter two mainly depends on the development of computer hardware. The appearance of the graphic processor provides hardware support for solving the real-time problem of 3D visualization. Its unique programmable technology greatly improves the visualization of the calculation speed. Using the programmability of the image processor to accelerate the volume rendering algorithm has become the mainstream research direction. Such as literature[4] proposes a framework for interactively rendering three-dimensional data cubes using distributed ray casting and volume tiles on a cluster of workstations supported by one or more graphics processing units and a multi-core central processing unit. Literature[5] analyzes the interactive visualization of gigabyte volume data on GPU, proposes a new classification of large-scale visualization technology based on GPU, and uses the current subset of data to generate the desired output image display resolution. Literature[6] proposes a distributed multi-node GPU-accelerated parallel rendering scheme for seamlessly coupling low-level computing environments and advanced visualization software to provide stable and efficient operation support for multi-GPU ray casting volume rendering in visual clusters.

The above methods rely on hardware support for accelerating the ray casting algorithm. Although the volume data of the input volume data set is large, the rendering speed is still significantly improved. However, the above method has not been improved from the principle of the volume rendering algorithm itself. The re-sampling in the ray casting algorithm and the trilinear interpolation of the re-sampling point[7] are the main reasons for restricting the rendering speed. How to reduce the complexity and the amount of computation in the re-sampling process is an important method to improve the rendering speed. This paper proposes an improved ray casting acceleration method based on the principle of the algorithm. This paper proposes an improved ray casting acceleration method based on the principle of the algorithm, adjusts the size of the back-stepping step according to the set threshold range, adaptively determines the interpolation sampling point and performs compound interpolation on the determined sampling point. Fewer sampling points and more appropriate interpolation methods reduce the amount of calculations, speed up the re-sampling process, and increase the drawing speed on the premise of ensuring the imaging quality.

1 Ray casting algorithm overview

The ray casting algorithm proposed by M. Levoy[8] is a direct volume rendering algorithm based on image sequences. The realization principle is that, starting from each pixel of the screen of the image space, a ray is emitted according to the set line of sight direction. When the ray passes through the volume data field, sampling is performed at a fixed step size. Calculate the color value and opacity of the sampling point by trilinear interpolation from the color values and opacity values of the eight data points closest to the sampling point, and then follow all the sampling points on the ray from forward or backward. The synthesis is performed sequentially to obtain the pixel value of the light emitted on the current image, and the algorithm principle is shown in Fig. 1.

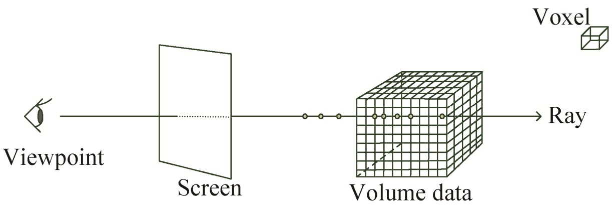


Fig. 1 Basic principles of ray casting algorithm

2 Improved ray casting algorithm

2.1 Interpolation algorithm

The most commonly used interpolation algorithms in volume rendering are nearest neighbor interpolation, linear interpolation[9], cubic convolution interpolation[10], and spline interpolation[11]. Although the calculation accuracy of cubic convolution interpolation and spline interpolation is high, the calculation amount of the algorithm is large. However, polynomial interpolation and Lagrange interpolation have high computational complexity and are generally only used to render specific higher quality images.

The nearest neighbor interpolation algorithm is the simplest of the classical interpolation algorithms, and the optical attribute value of the sampled point is obtained from the optical attribute value of the nearest known sample point. Although this algorithm is the simplest, the accuracy is not high. This interpolation algorithm is suitable for interpolation calculation of gray continuous regions, and the operation speed is very fast.

Linear interpolation includes one-dimensional linear interpolation, bilinear interpolation, and trilinear interpolation. Bilinear interpolation and trilinear interpolation refer to one-dimensional linear interpolation in two-dimensional space and three-dimensional space, respectively. The interpolation process of one-dimensional linear interpolation is shown in Fig. 2. Assume that A and B are two adjacent voxels, V_A and V_B are their corresponding voxel values, C is the re-sampling point, and the C point corresponding voxel value V_C can be calculated by the following formula:

$$\begin{cases} V_C = V_A \cdot \alpha + V_B(1-\alpha) \\ \alpha = \dfrac{CB}{AB} \end{cases} \tag{1}$$

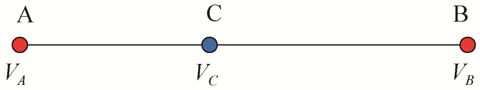


Fig. 2 One-dimensional linear interpolation

The most popular interpolation function in volume rendering is the trilinear interpolation. The trilinear interpolation refers to one-dimensional linear interpolation along the x-axis, y-axis, and z-axis on the regular cubic mesh data. As shown in Fig. 3. Assuming that the data values of the eight vertices in the three-dimensional grid volume data are known as $v_i(i=0,1,2,3,4,5,6,7)$, and the value of the sampling point q in the cube can be calculated using the following three-linear interpolation formula:

$$\begin{cases} p_1 = v_3 y + (1-y)v_6 \\ p_2 = v_2 y + (1-y)v_7 \\ p_3 = v_1 y + (1-y)v_5 \\ p_4 = v_0 y + (1-y)v_4 \end{cases} \tag{2}$$

$$\begin{cases} q_1 = p_1 x + (1-x)p_2 \\ q_2 = p_4 x + (1-x)p_3 \end{cases} \tag{3}$$

$$v_q = q_1 z + (1-z)q_2 \tag{4}$$

x、y and z are linear ratios, and equations (2) and (3) are brought into equation (4) to obtain the values, it can also be expressed by the following formula:

$$\begin{aligned} v_q = {} & v_3 xyz + v_6 x(1-y)z + v_2(1-x)yz + \\ & v_7(1-x)(1-y)z + v_0 xy(1-z) + \\ & v_4 x(1-y)(1-z) + v_1(1-x)y(1-z) + \\ & v_5(1-x)(1-y)(1-z) \end{aligned} \tag{5}$$

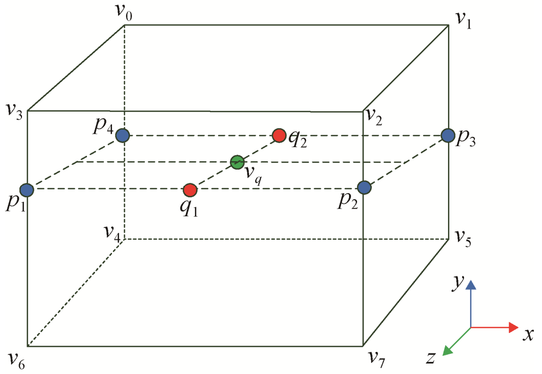


Fig. 3 Trilinear interpolation

Trilinear interpolation can be decomposed into 7 linear interpolations, and a linear interpolation requires 2 multiplications and 2 additions. Calculating a new re-sampling point in three-dimensional space requires 24 multiplications and 14 additions. If the time required for a multiplication calculation is t_1 and the time required for an addition operation is t_2, then the calculation time required for one-dimensional linear interpolation is Y, and the time required for a trilinear interpolation is K, so Linear interpolation is much more computationally expensive than linear interpolation.

If the time required for a multiplication calculation is t_1 and the time required for an addition operation is t_2, then the calculation time required to perform a one-dimensional linear interpolation is denoted as T_1, it can be expressed as $T_1 = 2t_1 + 2t_2$: and the time required for trilinear interpolation T_2 Can be expressed as $T_2 = 24t_1 + 14t_2$, so the trilinear interpolation computational complexity is much higher than the linear interpolation. The number of rays in the traditional ray casting algorithm depends on the resolution of the image, and N samples need to be sampled for each ray. Since the number of sampling points N during the actual re-sampling process is quite large, the use of trilinear interpolation to calculate the optical attribute values of the sampling points is quite time consuming, so this process is also one of the important reasons constraining the volume rendering rate.

2.2 Adaptive Compound Interpolation

Effectively reducing the number of redundant sampling points and reducing the complexity of the interpolation algorithm are the main methods to solve the long sampling time and large amount of calculation. Traditional ray casting algorithms sampled in fixed steps, the disadvantage is not only a large amount of calculation, but also for the important areas of interest and uninterested areas using a consistent sampling step for sampling, interpolation processing is necessarily unreasonable. This may lead to insufficient sampling of important areas or oversampling of non-critical areas. Affects the quality of reconstructed images and reduces the speed at which images are rendered.

Before the three-dimensional visualization, the three-dimensional volume data set is first classified. Suppose that the volume data set V contains m kinds of substances, which respectively give color values and opacity values to the m types of substances. The color values and opacity values of the ith type substances are (C_i, α_i), i=1, ..., m. If the volume data set contains m substances, the color value of these substances after classification can be expressed as $C_1, C_2, \cdots, C_m$, and the opacity value can be expressed as $\alpha_1, \alpha_2, \cdots, \alpha_m$. There are correlations between neighboring voxels in the volume data set. These voxels have similar optical attribute values after being mapped by transfer functions. According to this characteristic, the sampling points on the ray can be grouped, the optical attribute values of the sampling points in different groups can be analyzed, and a reasonable sampling step length and interpolation method can be set. This reduces the computational complexity of the interpolation algorithm and increases the speed and efficiency of re-sampling.

Because the complexity of general medical data is not high, there are few types of substances included, and there is connectivity between similar medical material data and similar substances. Using the principle of connectivity of matter, these similar substances are treated in the same group to reduce the complexity of the process. The N sampling points on the ray are grouped, each n sampling points as a group, which is divided into N/n groups. If the last group is less than n sampling points, it is processed according to the traditional ray casting algorithm. First, a threshold is set for the color value and the opaqueness value of the classified substance. Secondly, the n sampling points in each group are processed, and the trilinear interpolation is used to calculate the color values and opacity values of the first sampling point and the nth sampling point in each group, and the optical properties of the sampling points at two locations are compared. The range of value differences is used to determine if they are the same, similar substances, and similarities. The number of interpolated sampling points is determined by re-sampling the back-sample step size according to the belonging threshold range. Finally, compound interpolation is performed on the selected interpolation sample points.

Assume that ε, δ, $\varepsilon \in (0,30]$, $\delta \in (0,0.2]$. Set the number of interpolated sample points in each group to be a, the interpolated value in the group to reduce the time to b, and the sampling step length is S. The following operations are performed on the sampling points in each group. The sampling initial point S = 1 takes the sampling point g_1, and the sampling step length is adjusted to n times the initial step length and the sampling point g_n is taken. In order to ensure the sampling precision within the group, a trilinear interpolation algorithm is applied to the sampling points at both ends of the group. The color values are denoted as C_1^*, C_n^* respectively, and the opacity values are denoted as α_1^*, α_n^*.

(1) If $0 < |C_1^* - C_n^*| < \varepsilon$ and $0 < |\alpha_1^* - \alpha_n^*| < \delta$ are true, the above two inequalities are satisfied, this group of voxels has a large similarity. After removing the sampling points at both ends of the group, the remaining n-2 sampling points in the group can skip some of the selected points and adjust the sampling step to skip complicated trilinear interpolation. Under this condition, sampling points that need to be

interpolated in the group can be back-sampled by a single step (S=3) that is tripled and a one-dimensional linear difference can be made.

(2) If $\varepsilon <| C_1^* - C_n^* |< 2\varepsilon$ and $| \alpha_1^* - \alpha_n^* |< \delta$ are true, then change to double the single step (S=2) to select the interpolation sampling point for one-dimensional linear interpolation.

(3) If $| C_1^* - C_n^* |> 2\varepsilon$ or $| \alpha_1^* - \alpha_n^* |> \delta$ is true. It shows that the attribute values of the voxels in the group are quite different. It needs to be fully sampled and accurately calculated. The single-step long sampling is performed in the traditional way and the value of the re-sampling point is calculated using the trilinear interpolation algorithm.

Compared with the traditional sampling interpolation algorithm, after grouping and performing variable step-length retreat to select sampling points, the reduced number of sampling points for each group of interpolated values can be expressed as: $N_i = n - \left(\left\lfloor \frac{n-1}{S} \right\rfloor + 2 \right)$. If $\frac{n-1}{S}$ is an integer, indicating that the last selected sampling point coincides with the first sampling point in the group when selecting the interpolation sampling point backward, then $N_i = n - \left(\left\lfloor \frac{n-1}{S} \right\rfloor + 2 \right) + 1$, $\Delta T = (n-2)T_2 - (N_i - 2)T_1$.

In this paper, the intra-group variable step size selects the interpolated sample points for compound interpolation. Although the complex trilinear interpolation and sampling process is greatly optimized intuitively, when the amount of data is large, more structural information needs to be displayed in the image. In other words, when a large number of sampling and interpolation calculations are needed, the speed advantage of this method will be clearly reflected, providing a solution for real-time rapid volume rendering.

3 Experimental results and analysis

In the experiment, the volume data is foot data and head data. The data format is .RAW, and the data size is 256×256×256. Computer configuration: Hardware configuration: The processor is Intel(R) Core(TM) i5-4210H CPU @2.90GH, memory capacity is 4.0GB, and the graphics card is NVIDIA GeForce GTX 950M software configuration: Microsoft Visual C++ 6.0 and OpenGL.

When grouping the volume datasets, there are too few sampling points in each group, and the re-sampling process is not optimized too much. The interpolation process is still time consuming and it is difficult to meet the condition of increasing the sampling step by stepping back, resulting in an acceleration effect not obvious. There are too many samples in the group after grouping, and there are too many interpolation sampling points skipping after adjusting the step length of sampling. The computational amount of the interpolation algorithm is significantly reduced and the rendering speed is accelerated, but at the same time it may cause a decrease in sampling accuracy and impair the quality of the rendered images.

This paper carries out experimental verification for n=5, 6, 7, 8, 9, 10 respectively. The results are shown in Fig. 4. As the value of n increases, the rendering time gradually decreases. When the value of n is 8, 9, 10, the acceleration effect is better than the previous group. However, when grouping by this method, when *n*=10, the backstep sampling S is adjusted to 3, the overlap of the sampling points can be overlapped. When n=9 and S=2, the same phenomenon can occur. Therefore, the final value of n chosen for this experiment is 8.

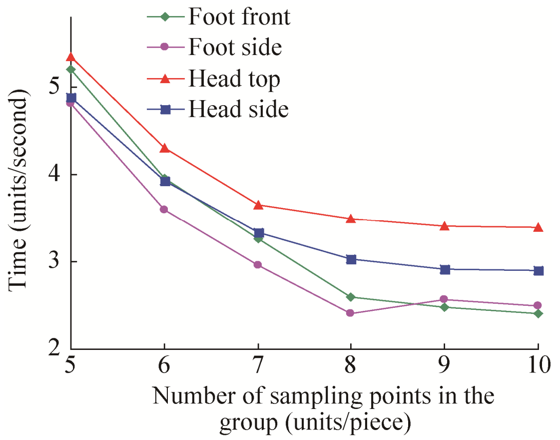
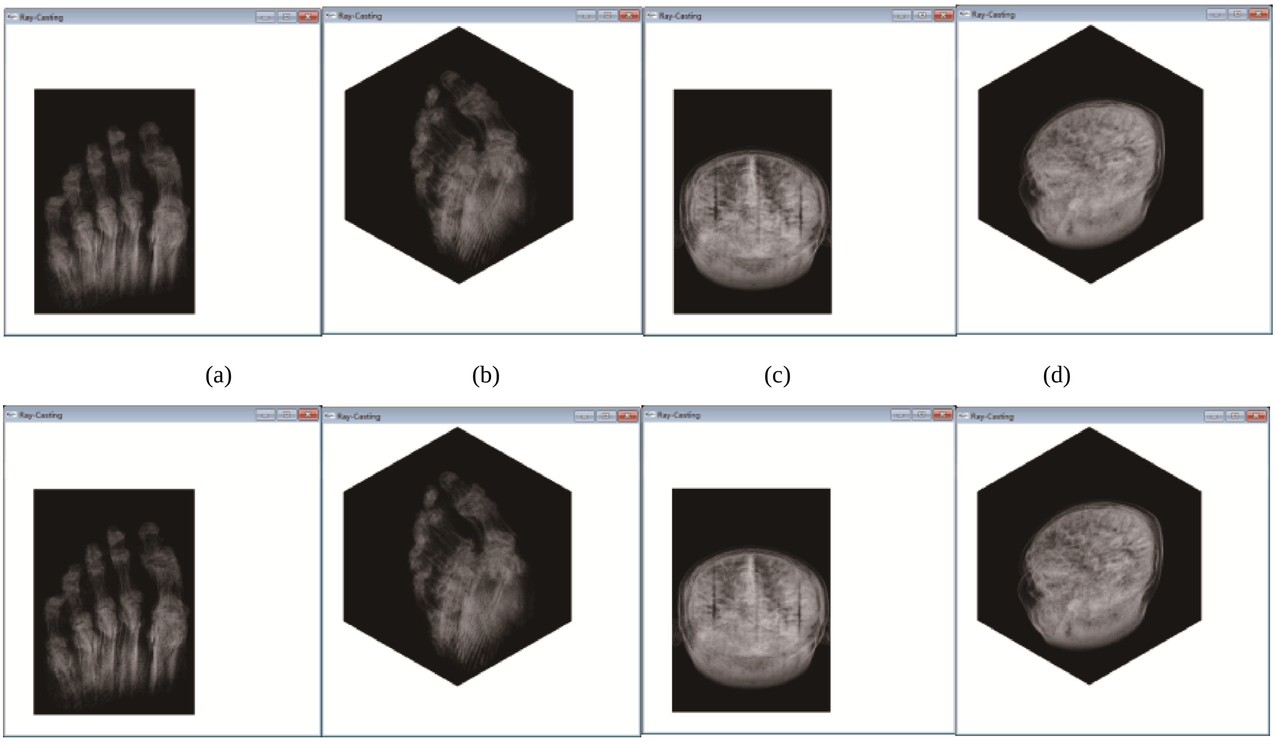


Fig. 4 Comparison of the number of samples in the group

Fig. 5 is a medical visualization effect image using a conventional ray casting method and an improved method (n=8) herein. Fig. 5(a) to (d) are three-dimensional images obtained using a conventional ray casting algorithm, and (e) to (h) are three-dimensional images rendered after the improvement of the conventional method in this paper. The experimental results show that there is no significant difference in the visual effects of the two methods, indicating that the improved method has no significant loss in image quality.

Tab. 1 compares the rendering time of the volume data sets used in this experiment with the traditional ray casting method and the improved method in this paper. To verify this method, the two selected data sets are verified from two viewpoints. Although the data size is the same, when the viewing angle is changed, the amount of image information displayed in the image changes, and the head information data is much larger than the foot data. That is, with the same image resolution, the number of effective rays emitted from each pixel of the image increases, and the effective sampling points of voxels in the ray and data fields increase, which verifies the effectiveness of the new method proposed in this paper.



(a) (b) (c) (d)

(e) (f) (g) (h)

Fig. 5 Medical Image Visualization Image

Tab. 1　Visualization time comparison of volume data　/s

Foot	Traditional	method	Improved	method	Speedup	ratio
Data size	Front	Side	Front	Side	Front	Side
(256×256×256)	6.245	5.229	2.613	2.436	2.39	2.15
Head	Traditional	method	Improved	method	Speedup	ratio
Data size	Top	Side	Top	Side	Top	Side
(256×256×256)	8.432	6.975	3.499	3.033	2.41	2.3

4 Conclusion

In this paper, based on the fixed single-step sampling of the traditional ray casting algorithm, all sampling points on the ray are divided into groups, and each n sampling points are divided into one group. Set the optical attribute threshold based on the connectivity of the same substance in the volume data set, compare the optical attribute values of the sample points at each endpoint, determine the similarity of the optical attributes of the sampling points within the group, adjust the step length of the back sample, and select the interpolation sampling points, and compound interpolation of sampling points within the group. Reasonably choose the number of sampling points, select sampling points for interpolating the sampling points in the group and retreat the sampling steps, optimize the re-sampling process, reduce the complexity of the algorithm in the interpolation process, and reduce the amount of calculation. In the case of ensuring that the quality of the drawing is not significantly lost, the drawing speed of the algorithm is improved.

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