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Short Paper

Local Detail Enhancement for Volume Rendering under Global Illumination

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Abstract

We present a novel method for realistic perception enhanced volume rendering. Compared with traditional lighting systems, that either tend to eliminate important local shapes and details in volume data or cannot offer interactive global illumination, our method can enhance the edges and curvatures within a volume under global illumination through a user-friendly interface. We first propose an interactive volumetric lighting model to both simulate scattering and enhance the local detail information. In this model, users only need to determine a key light source. Next, we propose a new cue to intensify the shape perception by enhancing the local edges and details. The cue can be pre-computed and thus we can still keep the rendering process running real-time. Experiments on a variety of volume data demonstrate that the proposed method can generate more details, and hence more realistic rendering results.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture

1. Introduction

Advanced global illumination, such as ambient occlusion (AO) [HLY10] and photon mapping (PM) [ZDM13], has become popular as a result of the development of interactive volume rendering. Compared to traditional local illumination, such as Phong model, the goal of these global models is to generate a more realistic effect to enhance the spatial perception of the volume data. However, the local shape perception of objects is often reduced, as the scattering may blur the boundaries of objects, leading to worse rendering results of shapes and details within the volume data. In this regard, it is necessary to propose an effective illumination method that can not only enhance the depth perception but also maintain local shape perception to improve the visual effect.

In principle, enhancing the perception of rendering indicates enhancing the contrast of brightness in the feature's location. Recent works have proposed to achieve such an enhancement by optimizing the light system design. However, these algorithms are either not efficient in terms of time-complexity or too complicated for users to determine the light source, position, and direction. For example, Wang et al. [WK14] proposed to employ three types of directional lights to enhance the visual cues of the rendering results, but it cannot achieve real-time rendering because whenever the viewpoint changes, the light source needs to be re-designed, which is usually time-consuming. Zhang et al. [ZM13] proposed a lighting design method using a back light to highlight the rim and another point light to enhance the perception of volumetric features of interest. While it can achieve satisfactory results, the system is not friendly in terms of user interaction.

In this paper, we present a novel light system that can enhance the perception cues of the volume data and change the position of the key light interactively real-time. To achieve global illumination to enhance depth perception, we adopt an interactive volumetric lighting model to simulate scattering and shadowing [RDRS10]. Meanwhile, to avoid hard shadow, we propose an improved light model that can generate soft shadow to display details of volume effectively. Furthermore, inspired by some image processing algorithms, we propose a shape enhanced cue that use space structure of the volume data to enhance the edge and highlight the curvature.

The main contributions of our work can be summarized as:

- To enhance depth perception at different directions, we propose a novel light system that uses an interactive global illumination as the key light and a local illumination as the filling light.
- To enhance shape perception, we propose a novel cue that can enhance the edge and curvature of the volume data. In addition, the pre-computation of this cue makes the rendering real-time.

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2. Related work

Some visual enhancement methods for volume rendering have been presented earlier. The volumetric halo [BG07] is proposed to enhance depth perception. In recent years, global illumination techniques have been involved in volume rendering to enhance depth perception. Ambient occlusion (AO) [HLY10] is one of many global illuminations that simulate shadows by evaluating how nearby objects can occlude parts of ambient light. The Monte Carlo ray tracing method applied to volume rendering by Kroes et al. [KPB12] could achieve shadow and single scattering effects. Besides, photon mapping has also been applied and to achieve real-time rendering, Zhang et al. [ZDM13] combined volumetric photon mapping with the pre-computed radiance transfer pipeline.

For local shapes enhancement, Lee et.al [LHV06] suggested a method that first segments the objects into several local surface patches, and then places lights. However, this method is limited to surface rendering. Light Collages [CHV04] use multiple lights and local illumination to adaptively enhance the shape of different parts of the structures. Wang et al. [WK13] proposed a lighting system that enhances the visual cues of the volume data using shadow for depth perception and diffuse reflection for shape perception.

3. Method

Our light system uses an improved global illumination as the key light to enhance depth perception, and for local detail enhancement, a local illumination and object space enhanced cue based on object-space analysis are applied. In general, our pipeline consists of three parts: volume rendering, pre-processing of shape volume, and light volume calculation, which is shown in Figure 1. The shape volume, which is obtained by data volume, is pre-calculated before the process of ray casting, the calculating will not occupy the time of rendering and is used to object space enhancement. Besides, the light volume is used to simulate multi-scattering that can produce global illumination.

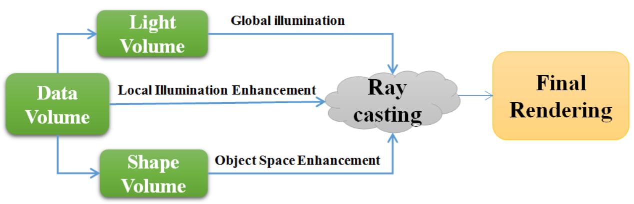


Figure 1: *The pipeline of the proposed method.*

After combining global illumination and local-enhancement, we obtain the lighting colour L_f for the final shading at the current voxel, which can be represented as:

$$L_f = \int_{4\pi} h(\omega_i, \omega_0) L_i(\omega_i) d\omega_i \cdot (L_{diffuse} + L_{ambient} + L_{specular}) \cdot S_{object} \quad (1)$$

where $h(\omega_i, \omega_0)$ donates the phase function at current voxel, and represents the radiance coming from direction ω_i and scattering into direction ω_0. $L_i(\omega_i)$ is the attenuated incident radiance from direction ω_i. $L_{diffuse}$, $L_{ambient}$, and $L_{specular}$ are the light colour of Blinn-phong that are used for local illumination enhancement, and S_{object} is the shape factor in the shape volume which produces the object space enhancement. To achieve real-time interactivity, our global illumination is also calculated in the volume space as [RDRS10].

3.1. Global illumination

Our light volume is generated using [RDRS10], which simulates light transmission as continuous slices and records the result in light volume, whose advantage lies in producing realistic global illumination and achieving real-time interactivity. However, it generates a hard shadow, which is not physically correct and hides the local details. Therefore, we propose an improved global illumination based on [RDRS10], albeit different from it. In our implementation, we do not separate the global illumination into indirect lighting and direct lighting, which is applied to produce harder shadow, and only use blurring (used for simulating multi-scattering) for chromaticity. Specifically, in our light propagation, we remove the shadowing propagation involving the voxel in the neighboring slice between current voxel and light source, and emphasize the scattering propagation that takes into account several voxels when the light travels form the light source through the volume slice-by-slice.

In a technique similar to our method, Zhang et al. [ZM13] also used global illumination in a light system. However, they applied the global illumination light at the back of object to enhance depth information, which strongly depends on the transfer function as the back-light does not work appropriately in the presence of substantial data with high-opacity at the back. Besides, the back-light does not produce depth perception from different directions. To overcome this shortcoming, we use a light source called "key light" that can produce depth information arriving from different directions of the light source adjusted by the user. For instance, if an object has a hole from left to right, we must apply global light at either left or right to produce depth information.

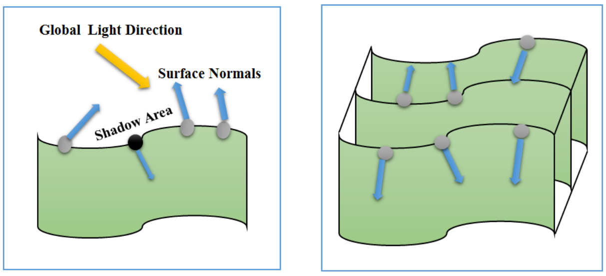
3.2. Enhancement of shape perception

Although global illumination can enhance the perception of depth information, it loses local shape and detail information, which are important in visualization. In surface display, normals are very important for enhancements of local details, calculated as gradient in volume rendering.

Local Illumination Enhancement. To enhance the rendering results' local shape under global illumination, we choose to put a local point light in front of the object to offer the local detail information. As shown in Figure 2 (a), the normal of the surface determines the local shape of the surface that contains the local details. However, in Figure 2 (b), we can see that the normals at points in the concave part are different from those at the surface because the normal of volume is decided by a local gradient vector. As the local gradient vector cannot produce shadow at a surface, thus, to avoid the inconsistency between the concave and convex, the diffused light is calculated as follows:

$$L_{diffuse} = |N(x) l(x)| k_d l_d \quad (2)$$

where $N(x)$ is unit normal vector, k_d is the diffuse reflection coefficient, l_d is light diffuse colour, and $l(x)$ is the normalized vector in the direction of the light source. Thus, we can display the points in different gradient directions. Nevertheless, the problem for the concave part of the surface still remains unsolved.



(a) (b)

Figure 2: *(a) Illustration of a surface: the yellow arrow is the direction of light and the blue arrows are the normal directions of points on the surface; and (b) illustration of a volume.*

Object Space Enhancement. In digital image processing, the most common method to enhance the details of the image is using a sharpened filter such as the Laplacian [GW01] operator which can add more information, not only about the edges and contour but also about the detail perception of the image. Using this as inspiration, we propose the other shape enhanced cue obtained by analysing the object space of volume data, as each pixel in the rendering image is formed by the sample points in the ray cast from the image pixel to the object.

We select $3 \times 3 \times 3$ point as a unit volume, which surrounds the sampling centre in the data volume. In each unit volume, the intensity of the central point has an effect on the local shape. Therefore, the local shape can be enhanced by applying data volume with a sharpened filter that can make up for the shortcomings of using local illumination, which can not solve the display of concave and raise the edges and contours:

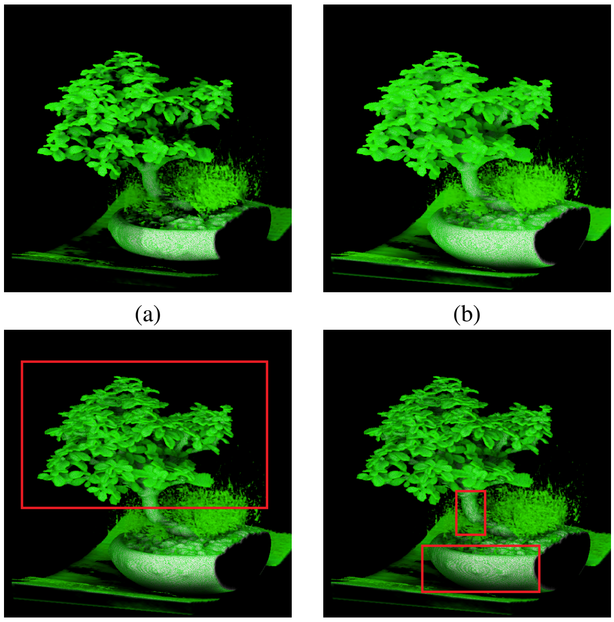
$$\bigtriangledown^2 f = [f(x+1,y,z) + f(x-1,y,z) + \cdots + f(x+1,y+1,z+1)] \\ - 26 f(x,y,z) \tag{3}$$

$$g(x,y,z) = f(x,y,z) - \bigtriangledown^2 f \tag{4}$$

where $f(x,y,z)$ is the intensity of the sampling point and $g(x,y,z)$ is the intensity after enhancement. Then S_{object} can be obtained by computing $g(x,y,z)+c$, where c is the factor to adjust the effect of object space enhancement. When $g(x,y,z)+c > 1$, it will be set as 1.

4. Experiment

Our method was implemented on a system with 3.50 GHz Intel Xeon E5-1620, 8GB Memory, and an NVIDIA Quadro K4200. The GPU-based ray-casting volume algorithm was developed to render the results using C++ and GLSL shading language. Experiments were performed on various datasets to demonstrate the effectiveness of the proposed method. The datasets were obtained from the volume library `http://www9.informatik.uni-erlangen.de/External/vollib`.



(a) (b)

(c) (d)

Figure 3: *Rendering results of bonsai: (a) the result of using [RDRS10], (b) the result of the proposed improved global illumination, (c) the result of the proposed global illumination plus local illumination enhancement, and (d) the result of the proposed global illumination plus object space enhancement.*

4.1. Global illumination

To validate the accuracy and prove the advantage of our global illumination (Section 3.1), a comparison between our result and the result of [RDRS10] is shown in Figure 3. The test volume data set is a scanned data from bonsai. Figure 3 (a) shows the rendering result using direct illumination and indirect illumination proposed in [RDRS10] whose shadow is too hard and cover several local details, such as the area at the bottom of the bonsai. Figure 3 (b) shows the rendering result obtained by using only our proposed global illumination, where the shadow is not as hard and the depth information is enhanced. This case shows our global illumination to be more effective in generating soft shadow, which can avoid blocking the details of volume data.

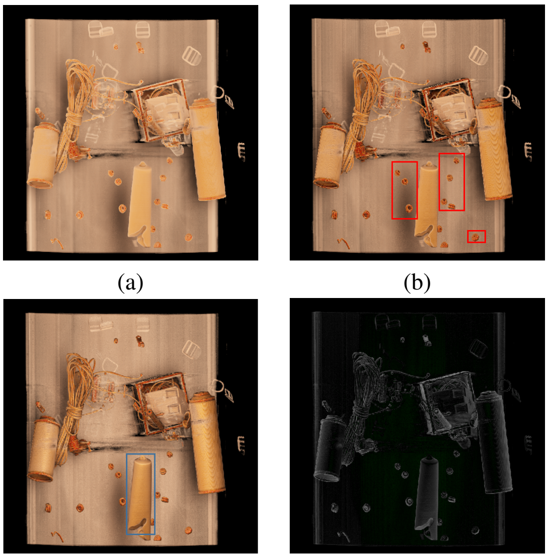
As mentioned, the light position is very important in depth information enhancement. Figure 4 shows the rendering results of a volume data of a male head, which was acquired from a CT scan with different light positions. Figure 4 (a)-(c) are the result obtained when the light source was placed at different positions between the upper left and lower left.

4.2. Shape enhancement

For some data sets, use of only global illumination can not achieve the effective visualizations, especially for those objects whose structure is complex. To show the effect of two cues that are local illumination enhancement and object space enhancement separately, we also use the volume data set of bonsai. Figure 3 (c) show the results in which the local illumination enhancement is added,

(a) (b) (c)

Figure 4: *Results with different light positions.*



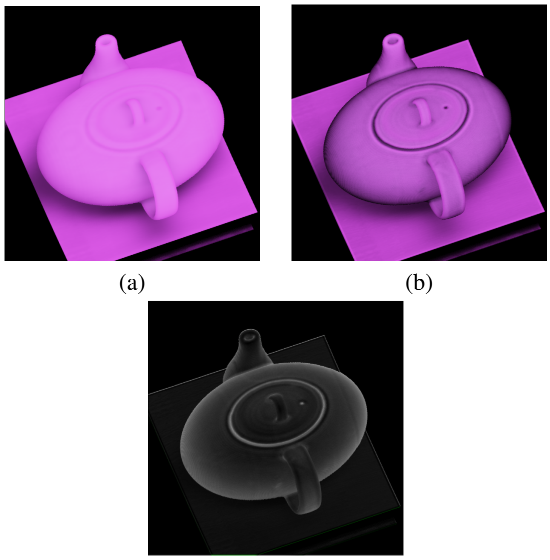
(a) (b) (c) (d)

Figure 5: *Rendering results of a backpack: (a) rendering result using the proposed global illumination, (b) rendering result using object space enhancement, (c) rendering result using both object space and local illumination enhancement, and (d) the absolute difference between (a) and (c), demonstrating the enhanced details.*

which results in the obvious enhancement in the shape of the leaf. The result using object space enhancement is shown in figure 3 (d) where the stones' shapes in the pot are enhanced. This case shows our global illumination is more effective to generate soft shadow, and our shape enhanced cues, which include local illumination and space enhancement of volume can also enhance the display of the details.

In some cases, both the local shape and the object space need to be enhanced. The backpack is difficult to visualize using only key global illumination, as shown in figure 5(a) where some details of the volume data set are lost. Figure 5(b) is the rendering result adding the object space enhancement, where the shape details are enhanced especially the shape of the screws which is highlighted in the red box. Figure 5(c) is the result of adding both local illumination and object space enhancement under global illumination. When compared with the previous result obtained by adding only object space enhancement, the shape of the tube, which is highlighted in the blue box is also enhanced.

The edge of an object is also an important visual cue to enhance



(a) (b) (c)

Figure 6: *Rendering results of a teapot using our method (a)shows the result using our proposed global illumination,(b) shows the result using object space enhancement and (c)shows absolute difference between (a) and (b),the portion of white color demonstrating the enhanced details.*

shape perception, as shown by the results obtained when the data set of a teapot was used in one of our experiments. Figure 6 (a) shows the rendering result when using only global illumination. The depth information is enhanced but the shape details are blurry. Figure 6 (b) shows the result after adding the space enhancement cue, where the edge of the teapot lid is stressed, and the depth information exists as well.

Figure 7 shows a comparison between our method and [RDRS10]. In Figure 7 (c), the green colour shows the part that is covered by hard shadow. In Figure 7 (a), the local detail is vague. As Figure 7 (d), (e) and (f) show, when the factor c increase, the effect of object shape enhancement further weakness. Figure 7 (d) shows that although the details are clearer when c is set to a minimum value of 0.1, this result is accompanied by enhancement of noise. Thus, in our experiment we will use factor $c = 0.3$.

4.3. Performance

Our method can achieve real-time rendering under the existence of both global illumination as well as when shape cues are set. The performance timings for different data sets used in our experiment are listed in Table 1. Real-time rendering is achieved even when the volume is of size $512 \times 512 \times 373$. It is evident that our two shape enhanced cues do not consume time, especially object space enhancement.

Limitations. First, it is possible that the enhancement algorithm also enhances noise to some extent, though in most cases this has no obvious adverse effect on the rendering results. Second, shape enhancement depends on the transformation function, which may be tedious for users to adjust in some cases.

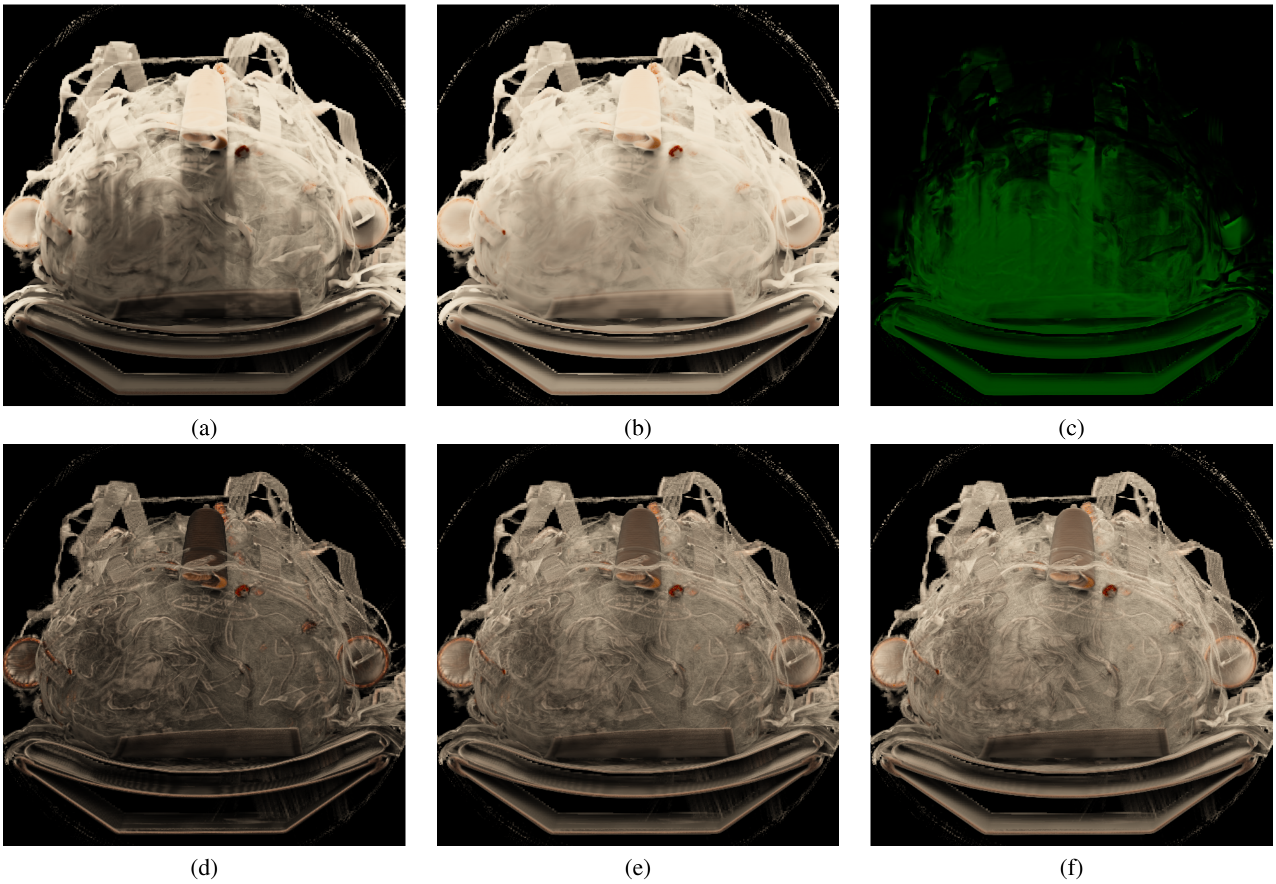


Figure 7: *(a) the result of using [RDRS10], (b) the result of our improved global illumination, (c) the absolute difference using (b) minus (a). The (d), (e), and (f) show results of our entire method with c = 0.1, 0.3, and 0.6, respectively.*

Table 1: *Performance measurements for volume data sets (frame per second).*

Volume	Data size	GI[a]	GI+L[b]	GI+O[c]	GI+L+O
Bonsai	$256 \times 256 \times 256$	33.6	28.4	29.9	28.2
Backpack	$512 \times 512 \times 373$	20.3	18.5	19.4	18.4
Teapot	$256 \times 256 \times 178$	41.6	40.3	41.5	39.6
Male head	$128 \times 256 \times 256$	43.4	41.5	42.6	41.1

[a]Global Illumination. [b]Local Illumination Enhancement. [c]Object Space Enhancement.

5. Conclusion and future work

We proposed two novel shape enhancement schemes under global illumination. Our system can not only make users obtain the depth and shape information by changing the direction of light but also enhance the shape information. Our method can help explore volume data and recognise the relationship between different structures more clearly. Future investigations include adding a module to distinguish feature and noise in the volume data to avoid enhancing noise in the rendering results and further improving the interaction of the proposed system by intelligently determining some parameters.

Acknowledgments

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