Ray Tracing Method Based on Spectral Distribution for Reproducing Realistic Images

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Abstract

The current paper proposes an improved reproduction algorithm that can produce a realistic image of a real scene based on the spectral distribution of light and objects, as perceived by human eyes. First, a backward ray tracing method is used where the spectral distribution of objects and illuminants is used to represent the physical characteristics in the real world. Next, an improved shading model is proposed based on applying Bouguer-Beer's law to consider the optical absorptive property of transparent objects. Finally, instead of a constant ambient light term, a new ambient light term is defined that considers the diffuse reflection of neighboring objects.

Introduction

Rendering is the process that realistically depicts a 3D model through the display of shaded surfaces, thereby enabling a 2D image to be reproduced from a scene viewed in 3D space. Rendering techniques can be divided into two classes, according to what they are based on Ref. [1]: image-based rendering (IBR) and physical-based rendering(PBR). Basically, IBR methods generate arbitrary views of a scene from many images acquired by observing a real object. Although IBR methods can model lighting without geometrical information and are independent of scene complexity, the main disadvantages are the large amount of space required to store the images and the acquisition of consistent images of real scenes without noise. With the recent rapid growth of 3D computer graphic techniques, research on indirect experience through virtual environments and modeling before product development has dramatically increased. Thus, to produce a realistic image of a specific product, a PBR method is used that includes an accurate geometrical model and the spectral characteristic of the materials and light sources.

In the current paper, the backward ray tracing method is used to generate a realistic image.[2] For a more accurate reproduction, as perceived by human eyes, the Hall shading model is modified to include the spectral characteristics of the light sources and materials, instead of simply the three RGB channels. For transparent colored objects, the optical absorptive property is considered by applying Bouguer-Beer's law.[3]

Whereas the term ambient light is typically constant in generic shading models, a new ambient light term is approximated based on considering the diffuse reflection from neighboring objects. As a result, the shading model can simulate accurate reflection, refraction, and light absorption according to various light sources and objects. Simulation results show that the proposed algorithm can reproduce images that are visually similar to human perception.

Spectral-Based Backward Ray Tracing

Ray tracing techniques model the interaction between light and objects within a scene, thereby increasing the realism of images through perspective, shadowing, reflection, refraction, and texturing.

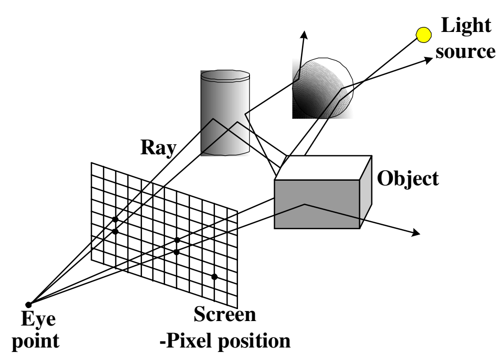

Figure 1. Concept of backward ray tracing

Backward ray tracing is where rays are cast from the eye into the environment. As such, backward ray tracing, as shown in Fig. 1, identifies incident light energy based on tracing rays from the eye as the point of observation to the screen as the viewing space.[4,5] Therefore, the algorithm is very efficient and can reduce the computational cost, as it only traces the number of rays as fixed by the resolution size.

Light from a source will change its energy and spectral distribution due to reflection and transmission processes when traveling through various objects. As such, these physical transformation procedures of light energy need to be traced in order to accurately estimate the colors that the human eye perceives. All objects have spectral characteristics that represent its particular color, while its reflectance and transmission characteristics represent its physical properties. The energy distribution of light reflected from an arbitrary object, as shown in Fig. 2, is the product of the spectral power of the light before arrival and the spectral reflectance of the object.

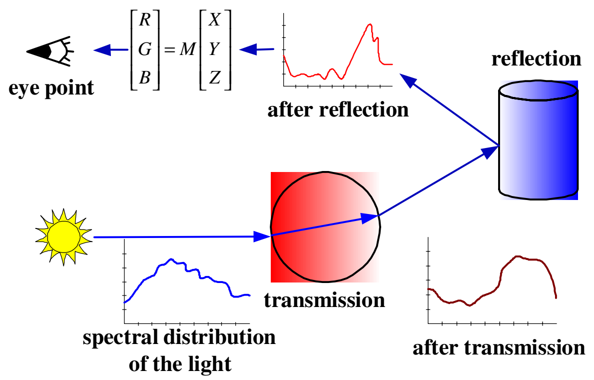

Figure 2. Calculation of color based on spectral distribution of light sources and objects

Finally, the light energy that the human eye perceives can be represented by tri-stimulus values and then converted into RGB values considering the particular display device. Therefore, the spectral characteristics of light and objects must be modeled accurately to make more realistic images using the backward ray tracing method. Cook used the spectral reflectance of materials to render specific materials, such as a copper vase and rubber. In the Hall shading model, a wavelength function is used to represent the spectral reflectance and transmittance. The current paper considers the physical property of light and objects by calculating optical phenomena, such as the illumination, reflection, and transmission based on the spectral distribution characteristic of each model. Accordingly, the proposed ray tracing method can render a realistic image by accurately modeling the physical phenomena that occur in the real world instead of calculating based on three general RGB primary colors.

Improved Hall Shading Model

The proposed physical-based shading model theoretically considers the optical absorptive property of the light energy and adds this factor to the Hall shading model. New ambient light is also determined by considering neighboring objects instead of using a constant ambient light so as to reproduce a realistic image as perceived by humans.

Conventional Shading Model

As a traditional shading model, the Phong specular reflection model is a good example of a shading technique arrived at empirically.[6] Phong uses Lambert's cosine law and $\cos^n \alpha$ to calculate a diffuse reflection and specular reflection, respectively, where α is the angle between the vector of the reflected light and the vector of the incident light and n is the coefficient that controls the intensity of the highlight. Although this model can reproduce quite good results and is simple to implement, it is not based on physics but rather on empirical observation. Blinn introduced a more accurate model for calculating specular reflection based on the theoretical model derived by Torrance and Sparrow instead of the $\cos^n \alpha$ used by Phong.[7,8] Blinn's model predicts the irregular reflection of real surfaces theoretically, and the derived functions and experimentally measured data were found to be very close. A further improved reflection model by Cook uses a color shift effect to generate more realistic images of metallic objects.[9] The Hall shading model attempts to represent the physical properties of an object and light source based on a function of the wavelength[10]. However, the model does not consider the optical absorptive property of transparent objects and only uses a simple factor for ambient light. Accordingly, the current paper improves this model by considering the absorptive property of objects and adding a new ambient light term that considers the effect of inter-reflection among neighboring objects.

Energy Absorption Factor Derived By Bouguer-Beer's Law

When a ray transmits a transparent and colored object, the ray is refracted and its energy reduced according to the property of the material. For transparent materials, knowledge about their absorption properties as a function of the wavelength can be used to estimate their color. Bouguer and Beer discovered that spectral transmittance could be transformed using logarithms to achieve a linear system. They performed a set of experiments using colored glass with different thicknesses, and according to Bouguer's experiment and proof, as shown in the following equation, there was an exponential relationship between the thickness and the spectral transmittance.

$$T_{\lambda,i} = t_\lambda{}^b \tag{1}$$

where $T_{\lambda,i}$ and T_λ are the internal spectral transmittance of a transparent object and the internal spectral transmittance relative to the unit thickness, respectively. For example, suppose a $3mm$ -thick transparent object with a 0.9 -transmittance relative to the unit thickness. If a ray transmits the object, the entire absorption is $t_\lambda{}^b = 0.9^3 = 0.729$. Thus, as shown in Fig. 3, increasing the thickness increases the amount of absorption according to the logarithmic transformation.

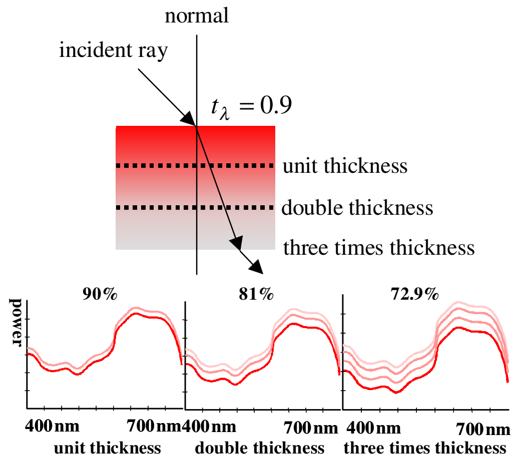

Figure 3. Reduction in energy of transmitted light according to object thickness

As a result, considering the absorption factor of the light energy allows the rendering algorithm to render transparent colored objects accurately.

New Ambient Light Considering Diffuse Reflection of Neighboring Objects

In many conventional shading models, the factor of ambient light is uniformly determined without considering the effect of the diffuse reflection of neighboring objects. Many shading models have limited the effect to a constant ambient term. Therefore, the current paper proposes a new ambient term where the ratio of the diffuse reflection of objects is also considered. Under enclosed conditions, such as walls, boxes, or opaque-colored objects, the color perceived by human eyes are significantly influenced by objects with a large diffuse reflectance. Thus, the constant ambient term, as denoted in the following equation, is replaced by the quantitative sum of the diffuse reflectance of the neighboring objects.

$$I_a(\lambda) = K_a \sum_i k_i R_i(\lambda)^{n'_i} \tag{2}$$

where $R_i(\lambda)$ is the spectral reflectance of the i th object, and n'_i and k_i are the diffuse factor and coefficient for the reflectivity of the i th object, respectively. The coefficient K_a controls the entire amount of ambient light. When applying equation (2) to the shading model, the resulting ray tracing method is able to consider the contribution of neighboring objects to the ambient light.

Physical-Based Improved Hall Shading Model

The objective of the proposed shading model is to consider the optical absorptive property of transparent objects. The proposed model does not use constant ambient light but rather generates new ambient light by applying the diffuse reflectance of neighboring objects. As such, the Hall shading model is improved as shown in the following equations.

$$\begin{aligned} I(\lambda) &= k_{st} I_I(\lambda) \times (F_{st}(\lambda) \times t_\lambda{}^b) \times \left((L \cdot N)^{n'}\right) \\ &+ K_a \sum_i k_i F_{st}{}^i(\lambda)^{n'} \end{aligned} \tag{3}$$

$$\begin{aligned} I(\lambda) &= k_{sr} I_I(\lambda) \times F_{sr}(\lambda) \times \left((L \cdot N)^{n'}\right) \\ &+ K_a \sum_i k_i F_{sr}{}^i(\lambda)^{n'} \end{aligned} \tag{4}$$

where $I(\lambda)$, $I_I(\lambda)$, k_{st}, and k_{sr} are the spectral energy at the intersection point, the spectral energy of the light source, and the specular coefficients for the refraction and reflection, respectively, $F_{st}(\lambda)$ and $F_{sr}(\lambda)$ are the spectral transmittance and spectral reflectance of the object, respectively, $(L \cdot N)$ is the dot product of the light source and normal vector of the surface, and n' is the highlight coefficient.

Computer Simulation and Results

The proposed spectral-based ray tracing algorithm was implemented based on the improved Hall shading model, including Bouguer-Beer's absorption factor and an ambient light term considering the diffuse reflectance of neighboring objects. Table 1 lists the parameters used for the simulation.

Table 1. Parameters Used for Simulation

parameters	Spectral-based method	RGB-based method
Illuminant	D65	RGB(1,1,1)
Transmittance, k_{st}	0.9	0.9
Reflectance, k_{sr}	0.1	0.1
Diffuse coefficient, n'	20	20
Index of refraction	1.3	1.3
Bougeur-Beer's factor	95%(unit)	-

The light energy represented by tri-stimulus values is converted into RGB values for displaying. In this computer simulation, the standard transformation matrix with 9300K reference white, as denoted in the following equation, is used for converting XYZ into RGB values.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = M \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 3.5181 & -1.4991 & -0.5181 \\ -0.8962 & 1.7525 & 0.0437 \\ 0.0798 & -0.2437 & 0.8931 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{5}$$

The resolution of the image is 640×480 in our simulation and as shown in following figure, we compare proposed spectral-based rendering method with RGB-based method.

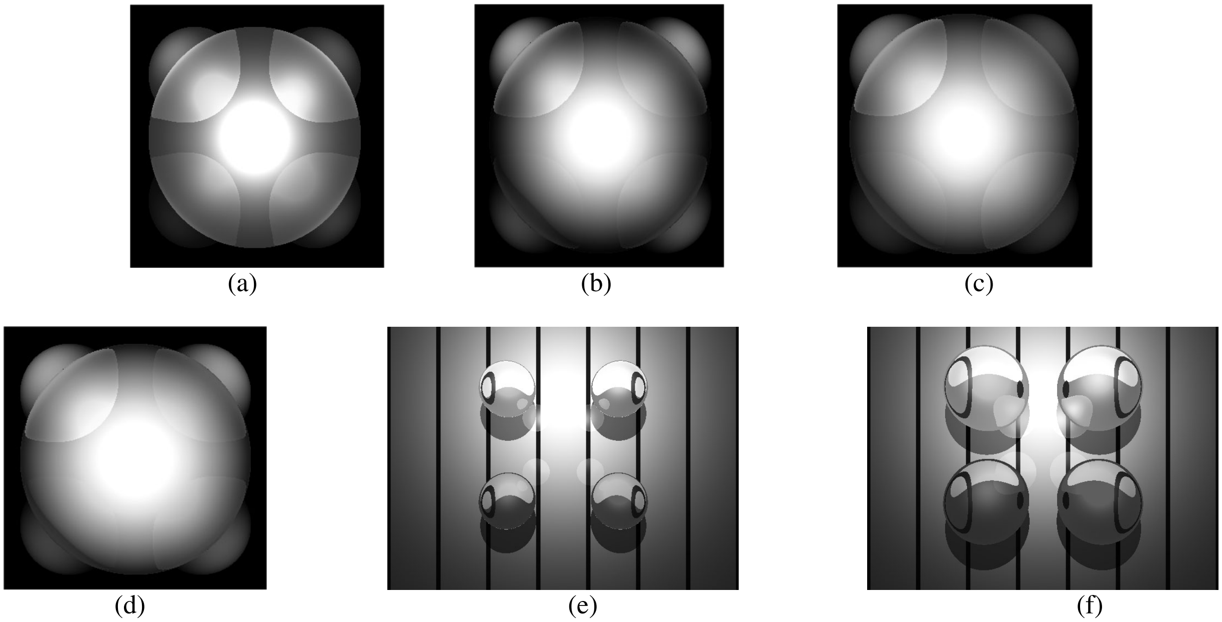

Figure 4. Rendering results. (a) RGB-based rendered image, (b) spectral-based rendered image, (c) rendered image when applying Bougeur-Beer's absorption factor, (d) rendered image with proposed ambient light, (e)-(f) rendered images with other models containing mesh background.

The RGB- and spectral-based rendering results are shown in Figs. 4 (a) and (b). In particular, the transmitted effects of sunlight appear in Fig. 4 (b). The results applying the improved Hall shading model considering the absorption factor based on Bouguer-Beer's law and a new ambient light term are shown in Figs. 4 (c) and (d), respectively. Figs.4 (e) and (f) show the results of the proposed spectral-based algorithm along with primitive and meshed objects.

Conclusions and Future Work

The current paper presented a spectral-based ray tracing method for reproducing realistic images as perceived by human eyes. As such, the spectral distribution representing physical characteristics is considered along with the absorption phenomenon of light energy. A new ambient light term is also proposed that considers the effect of the diffuse reflection of neighboring objects. The consideration of all these factors means that the resulting shading model can accurately simulate reflection, refraction, and light absorption according to various light sources and objects.

Future research will include accurate verification of this algorithm through physical experiments and consideration of the effect of inter-reflections.

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References

1. Thomas A. Funkhouser, "A Visibility Algorithm for Hybrid Geometry- and Image-based Modeling and Rendering," *Computers & Graphics*, vol. 23, pp. 719 - 728, 1999.
2. Andrew Woo, Pierre Poulin, and Alain Fournier, A Survey of Shadow Algorithms, *IEEE Computer Graphics and Applications*, vol. 10, no. 6, pp. 13 - 32, Nov. 1990.
3. Roy S. Berns, *Principles of Color Technology,* Wiley Interscience.
4. J. Arvo, "Backward Ray Tracing, " *Tutorial Notes on the Developments in Ray Tracing SIGGRAPH 86*, Aug. 1986.
5. Whitted J. T, "An Improved Illumination Model for Shaded Display, " *Comm. ACM*, vol. 23, no. 6, pp. 342 - 349, June. 1980.
6. Phong B, "Illumination for Computer-Generated Pictures," *Comm. ACM*, vol. 18, no. 6, pp. 311 - 317, 1975.
7. James F. Blinn, "Models of Light Reflection for Computer Synthesized Pictures," *Computer Graphics, Proceedings*, *Annual Conference Series ACM SIGGRAPH*, pp. 192 - 198.
8. K. Torrance and E. Sparrow, "Theory for Off-Specular Reflection from Rough Surfaces," *Journal of the Optical Society of America*, vol. 57, no. 9, pp. 1105 - 1114, 1967.
9. Robert L. Cook, "A Reflectance Model for Computer Graphics," *Computer Graphics*, vol. 15, no. 3, Aug. 1981.
10. Andrew S. Glassner, *"An Introduction to Ray Tracing,"* Morgan Kaufmann Publishers, Inc.