Rapid Simulation of Translucent Material with Contrast-Reversing Rendering

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Abstract

We present a rendering method to reproduce translucent appearances in real-time. Since the translucency is caused by complicated light behavior such as scattering and absorption, reproducing translucent material requires computationally expensive cost. Due to its computational cost, it is difficult to apply the digital mock-up with the computer graphics for the purpose of cost reduction and acceleration of developing products. In order to reproduce the translucent appearance rapidly, we focus on the contrast-reversing image processing. We embed this simple image processing method to the reflection model. Our proposed method can reproduce in real-time with almost the same appearance compared to commercial rendering software.

Introduction

Recent years, digital mock-up (DMU) with computer graphics (CG) is widely used for the purpose of cost reduction and acceleration of developing products. This DMU has advantages to reproduce various features by changing the shape, color, and material properties of product as trial product. When designers consider configurations of product, the transformation of vertex position in CG object can realize the change of shape, and control of the pixel color of CG polygon can also realize the change of appearance in DMU. Owing to the 3D digitizer, it is easy to measure the shape of object from real world to virtual world in CG. Moreover, a transformed shape according to user's idea is produced by 3D printer accurately. On the other hand, it is slight difficult to change and represent the appearance of object, since this appearance is deeply affected by subjective observation and perception. In order to express this perception numerically, many researchers make an effort to develop the reflection model in CG for appearance reproduction. The Phong reflection model is the most famous equation with diffuse and speculer parameters[1]. This model has a possibility to reproduce various appearances with gloss or matte perception. Especially, gloss perception caused by specular reflection has very important information for material perception, because we recognize whether the object surface is smooth or rough by the relative strength of gloss appearance. More detail formulations and many parameters in reflection model are proposed in order to express accurate gloss appearance. On the other hand, setting parameters of reflection model becomes complex and difficult for designers to control appearance.

Pellacini et al. proposed the simple numerical formulation to become easy to define the perceptual dimensions between the CG parameters (specular and roughness) and the perceptual strength by using 2D display[2]. Since their formulation is simple, it is very useful for users to control the gloss appearance of commercial products. Similarly, we developed 3D appearance reproduction system and quantified the material appearance as previous work[3]. Our results derived that perceptual dimensions proposed by Pellacini are also suitable for 3D representation. However, this approach of numerical formulation for material perception has a limitation that the parameters of CG model are only based on surface reflection such as diffuse and specular. The practical DMU with various appearances is able to change only surface reflection but inner optical behavior such as translucency and scattering.

In this paper, we improve our evaluation system for material perception by adding the change of translucency with simple operation. Our proposed method can change the translucency of object by using reversal operation of diffuse reflectance. This is a simple way to control the translucent appearance while specular reflection and surface roughness are retained and able to use for reproducing the appearance.

Related Works

The reproduction of CG is very useful to evaluate the appearance of final product in the process of DMU. These reproductions are created by rendering algorithm based on the dichromatic reflection models such as Phong, Torrance-Sparrow, Ward and Lafortune[2][4][5][6]. For example, an appearance of gold material can be reproduced by setting the appropriate diffuse and specular reflectance. But, this rendering system also needs to represent more material properties, i.e. transparency and translucency. Xiao et al. indicated that the effective cue of translucency depends on lighting direction and phase function as shown in Fig.1[7]. This figure shows the comparison between forward lighting translucent object and backward lighting translucent object. (It is Fig.10 in their paper). It is apparent that Fig.1(a) and Fig.1(b) are in a reversal condition about luminance of reproduced object. In order to reproduce the realistic appearance, they used volumetric Monte Carlo path tracing method based on radiation transfer equation[8]. Though this rendering method is sophisticated to reproduce the translucent object, the calculation cost may be very expensive. On the other hand, Jensen et al. proposed the dipole diffusion model, which is an approximation of scattering effects[9]. This model is widely used because it can reproduce translucent object rapidly compared with Monte Carlo path tracing. This dipole approximation model can generate realistic skin images, however, it is difficult to reproduce translucent appearance in consideration for the influence of backward lighting. Moreover, the reduction of calculation cost is required since the process of DMU needs real-time rendering.

Making a paradigm shift to the rendering for translucency, we focus on image processing method proposed by Motoyoshi[10]. He implied that simple image statistics or texture metrics are one of the cue for translucency. He found that reversing the luminance of reproducing object can represent translucency. This is a very simple way of image processing to reproduce translucent object. Though the gloss appearance is not considered in his method, his idea provides us with useful knowledge. Our purpose is representing translucency or transparency in real-time and control the appearance by changing parameters flexibly. In order to achieve this representation, we embed our idea of reversing the luminance to the rendering pipeline.

Method

In this chapter, we explain our proposed method for rendering optically transmissive object. As the previous work proposed by Xiao, many kinds of coefficients such as scattering, absorption, extinction are used to reproduce the translucency or transparency. These coefficients are very important for photon based rendering. For example, Monte Carlo path tracing can simulate accurate light transport. In exchange for accuracy, the photon based rendering requires long calculation time to reproduce the optically transmissive object, since an appearance of object is constructed as the summation of huge number of light path. In order to decrease this calculation process, we consider the volumetric rendering algorithm with complicate light behavior which is scattering(s), absorption(a), and extinction($t = s + a$). These optical phenomena are employed as parameters, and appropriate simplification and approximation are applied in our proposed method.

Simplification and approximation

Because photons are scattered in various directions in the photon based rendering, the calculation process becomes complicated. However, by limiting the point of view of the observer and the light source position, the range of scattering direction is reduced. We will explain this simplification with Fig.2.

Fig.2(a) shows the case of the light behavior in a transparent object where the light source is present in the same direction as the observer's viewpoint. In general, the scattering has an angular dependence represented by the phase function. Supposed that the scattering is equal in both forward and backward direction, the backward scattering observed from the viewing direction would be approximated as a half of the total scattering sL_i.

$$I_{front} = sL_i / 2. \quad (1)$$

where L_i is incident light and s is a scattering coefficient.

On the other hand, Fig2(b) shows the case of the light behavior in a transparent object where the light source is present in the opposite side. In this case, the observed light at the observer's viewpoint consists of forward scattering light and residual transmitted light that is subtracted extinct phenomenon such as absorption and scattering.

(a) forward lighting

(b) backward lighting

Figure 1: *Comparison between forward lighting and backward lighting*

$$I_{back} = L_i - L_i t + s L_i / 2. \quad (2)$$

where t is a extinction coefficient.

Since there is a common factor in Eq.1 and Eq.2, Eq.2 would be rewrited as Eq.3.

$$\begin{aligned} I_{back} &= L_i - t L_i + s L_i / 2 \\ &= L_i - (t - s) L_i - s L_i / 2 \\ &= L_i - a L_i - s L_i / 2 \\ &= L_i - a L_i - I_{front}. \quad (3) \end{aligned}$$

where a is an absorption coefficient, which has a relation $a = t - s$.

Eq.3 indicates that the intensity of light in backward lighting condition can be denoted by using the intensity of light in forward lighting condition. Here, if we assume that $L_i = 1$, and $a = 0$, the most simple condition of diffusion approximation is derived as Eq.4.

$$I_{back} = 1 - I_{front}. \quad (4)$$

Eq.4 indicates simple reversing of the I_{front}, which is resemble to the contrast-reversing image processing proposed by Motoyoshi.

Applying to the reflection model

Next, we introduce a technique to apply our idea to reflection model. Generally, the dichromatic reflection model has two terms, diffuse reflectance and specular reflectance, to describe the light transport. Even this model can represent various material appearance, it is difficult to apply the effects of backward lighting for the practical CG reflection model. However, the effects of backward lighting would be approximated by using the effects of forward lighting as derived in Eq.4. Therefore, we embed the idea of contrast-reversing image processing to our reproduction system. Here, the rendering engine of our system employs Ward's reflection model. Ward's reflection model is denoted by Eq.5.

$$f(\theta_i,\phi_i,\theta_o,\phi_o) = \frac{\rho_d}{\pi} + \frac{\rho_s}{4\pi\alpha^2\sqrt{\cos\theta_i\cos\theta_o}}\exp\left(-\frac{\tan^2\delta}{\alpha^2}\right) \quad (5)$$

where θ and ϕ denote the polar and azimuthal angles of the incident and reflected light directions respectively. α denotes spread of the specular lobe (hereinafter referred to as roughness), and δ denotes the halfway vector between the incident and reflected directions. In this equation, the diffuse reflectance ρ_d, the specular reflectance ρ_s and roughness α are controllable CG parameters in this research. Our system employs the OpenGL Shader Language(GLSL) to control the rendering pipeline. As shown in Fig.3, the output of rendering with Ward's reflectance model is calculated by pixel shader[11][12]. This pixel shader can calculate the sum of the three variable parameters of CG such as the ambient light, diffuse reflection and specular reflection in order to determine each pixel value.

Eq.6 explains genaral processes calculated in pixel shader.

$$\text{output} = \text{ambient} + \text{diffuse} + \text{specular}. \quad (6)$$

The diffuse term calculated by OpenGL can be regarded as the case of forward lighting. Therefore, the diffuse term can be assumed as the intensity of light, I_{front}. As a result of the embedding, the idea of contrast-reversing image processing to the reflection model can be denoted as Eq.7

$$\text{output}' = \text{ambient} + (1 - \text{diffuse}) + \text{specular}. \quad (7)$$

Hereafter, we refer to the term, 1 – diffuse, as "reversed diffuse reflectance". Eq.7 is used to reproduce the translucent material instead of Eq.6 and we investigate this reproduction in next chapter.

Implementation

As mentioned above the chapter, we propose the simple method for reproducing translucent material. Based on reflection model, our method can represent a various translucent appearance rapidly and change of gloss appearance. Here, we evaluate our method to conventional method by comparing the ability of translucent appearance. Fig.4(a) shows the result of reproduction by using our system. Fig.4(b) shows the result of reproduction by using the "SSS2" algorithm in the LightWave 3D(NewTek Inc). This rendering algorithm and software are used by Motoyoshi and Nagai et al. to study the cue for translucency[10][11].

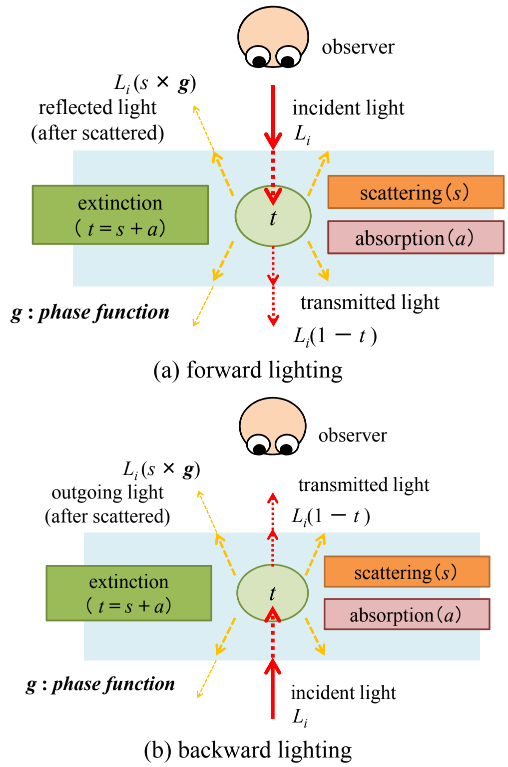

Figure 2: *Simplification of the light transport*

Though our system uses many approximations, it achieves to obtain almost the same appearance between Fig.4(a) and Fig.4(b). The "SSS2" algorithm in the LightWave3D has many parameters to change the appearance of reproduced object. The rendering takes about 10 seconds. In contrast, our system is easy to control the translucent appearance because we can change the appearance only by the replacement of reversed diffuse reflectance, specular reflectance and surface roughness by keyboard operation. Moreover, the material appearance including opaque appearance can be reproduced in real-time. Therefore, our system would benefit for designing tool obviously.

Here, it is noticed that there is a characteristic relationship between our method and Fresnel equations. For the transparent object, the edge of the object looks brighter due to effects of Fresnel reflection. By contrast with the opaque object, the edge of the object looks darker due to effects of shading. Since our system employs reversal operation of diffuse reflectance, this directly opposite phenomenon could be expressed between shading and Fresnel equations. We assume that this expression leads us translucent perception.

Let us discuss the parameters of reproduction. Fig.5(a) is a different case of reversed diffuse reflectance from Fig.4(a) while the specular reflectance and surface roughness are maintained as the same. Comparing Fig.5(a) to Fig.4(a), the part of body is darker and part of the edge is brighter since reversed diffuse reflectance is increased. Nagai et al. and Fleming and Bulthoff indicated that the edges or detail structure objects with high contrast pattern have more contribution to the translucency than the other region[12]. As one of the advantages, because our system can change specular reflectance, we can consider the effects of specular highlights on translucent material. Fig.5(b) has different surface roughness from Fig.4(a) while the reversed diffuse reflectance and specular reflectance keep the same number respectively. As the result of comparison between Fig.4(a) and Fig.5(b), these reproductions give us a different perception of material. The rendered object in Fig.4(a) looks like jade and the rendered object in Fig.5(b) looks like wax. The difference between these images is only surface roughness.

Discussion

Our proposed method can reproduce translucent appearance rapidly. Though this method uses many approximation, the difference between our reproduction system and LightWave3D is slight. In addition, comparing with dipole model approximation, our system can reproduce translucency very fast, therefore, our system would become a very useful tool for DMU and the other design tools. But, our system has some limitations. Constructing our method, we assume that the thickness of the object is constant. Thus, it is difficult for our system to reproduce the material with accounting for the thickness of object. Moreover, though the phase function is very important factor for translucent material appearance, our method regards this as isotropic scattering. Lighting direction is also limited in our system. Obliqueness lighting causes unnatural reproduction because our method is constructed by limiting the point of view of the observer and the light source position.

We realize that specular reflection has contribution to translucent material perception. Some previous works indicate that specular highlights are important for natural translucency[12]. The shape of specular highlights, such as strong and sharp or weak and dull, is not fully examined. Since our proposed method retains the parameters which describe appearance of specular highlights, it is efficient to investigate the effects of specular highlights on translucency as referring to numerical formulation proposed by Pellacini et al.[2].

Conclusion and future work

In this paper, we have presented the fast rendering method available for DMU. Applying the contrast-reversing idea to the dichromatic reflection model, our system can produce realistic translucent appearance rapidly compared to the previous works and commercial software. Though our method has some limitation, fast reproduction and maneuverable keyboard operation are very useful for material designing tool of DMU. In this work, we defined some parameters to approximate complicated light behavior of translucent object. To obtain more suitable results of reproduction for practical use, these parameters should be verified experimentally.

We also realize the various changes of specular highlights on translucent material perception. The effects of specular highlights would be controversial problem for translucent material perception. From a practical point of view, we need the investigation of relationships between appearance of objects and the reproduction parameters, including specular reflectance and surface roughness. This investigation would be useful in material design application to reproduce existing material efficiently.

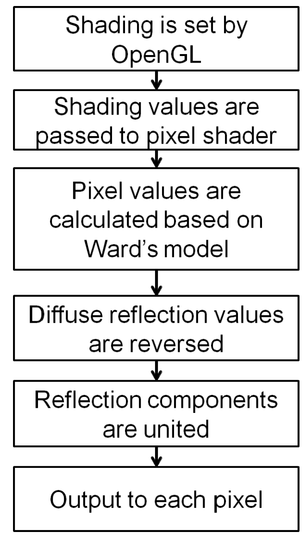

Figure 3: *Rendering process of our proposed method*

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References

[1] B. T. Phong, "Illumination for Computer Generated Pictures", Comm ACM, 18(6), pp.311-317 (1975).

[2] F. Pellacini, F. A. Ferwerda, D. P. Greenberg, "Toward a Psychophysically-Based Light Reflection Model for Image Synthesis", SIGGRAPH '00 Proceedings of the 27th annual conference on Computer graphics and interactive techniques, pp.55-64 (2005).

[3] S.Yamamoto, M.Sawabe, Y.Yamauchi, N.Tsumura, "Ascertainment of perceptual classification for material appearance", Color and Imaging Conference, 20th Color and Imaging Conference Final Program and Proceedings , pp. 94-99(6).(2012).

[4] K. E. Torrance, E. M. Sparrow, " Theory for Off-Specular Reflection From Roughened Surfaces", JOSA, Vol. 57, Issue 9, pp. 1105-1112 (1967).

[5] G. J. Ward, "Measuring and modeling anisotropic reflection", ACM SIGGRAPH Computer Graphics, 26(2), pp.265-272 (1992).

[6] E. P. F. Lafortune, S.-C. Foo, K. E. Torrance, D. P. Greenberg, "Non-linearapproximation of reflectance functions", SIGGRAPH '97 Proceedings of the 24th annual conference on Computer graphics and interactive techniques, pp.117-126 (1997).

[7] B. Xiao, B. W. Walter, I. Gkioulekas, T. Zickler, E. Adelson, K. Bala, "Looking against the light: how perception of translucency depends on lighting direction". Journal of Vision. 14(3): 17. (2014).

(a) Rendered image by our proposed method

(b) Rendered image by LightWave3D

Figure 4: *Comparison of two ways of rendering*

(a) Rendered image by changing reversed diffuse reflectance

(b) Rendered image by changing reversed surface roughness

Figure 5: *Result of our proposed method with different parameters*

[8] A. Ishimaru, "Wave propagation and scattering in random media and rough surfaces". Proceedings of IEEE, 79(10), 1359-1368 (1978).

[9] H. W. Jensen, S. R. Marschner, M. Levoy, P. Hanrahan, "A Practical Model for Subsurface Light Transport", Proc.of the 28th annual conference on Computer graphics and interactive techniques, pp.511-518, (2001).

[10] I. Motoyoshi, "Highlight-shading relationship as a cue for the perception of translucent and transparent materials". Journal of Vision, 10(9):6, 1-11, (2010).

[11] T. Nagai, Y. Ono, Y. Tani, K. Koid, M. Kitazaki, S. Nakauchi, "Image regions contributing to perceptual translucency" A psychophysical reverse-correlation study. i-Perception, 6, 407-429(2013).

[12] R. W. Fleming, H. Bulthoff, "Low-level image cues in the perception of translucent materials". ACM Trasactions on Applied Perception (TAP), 2(3), 346-382(2005).

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