Acquiring Curvature-Dependent Reflectance Function from Translucent Material

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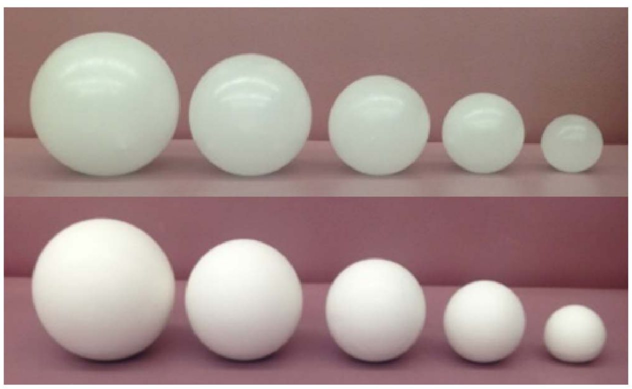

Figure 1. Translucent spheres made of wax (top) and soap (bottom)

***Abstract*—Acquiring scattering parameters from real objects is still a challenging work. To obtain the scattering parameters, physics-based analysis is ineffective because huge computational cost is required to simulate subsurface scattering effect accurately. Thus, we focus on Curvature-Dependent Reflectance Function (CDRF), the plausible approximation of the subsurface scattering effect. In this paper, we propose a novel technique to obtain scattering parameters from real objects by revealing the relation between curvature and translucency.**

***Keywords*-subsurface scattering; BRDF; inverse rendering; curvature;**

I. Introduction

Acquiring optical parameters from a real object is significant to synthesize realistic computer graphics images of various materials. However, it is difficult to obtain the parameters, especially from translucent objects because of its complicated behavior of the light transport inside the objects known as subsurface scattering. On the other hand, the effect of subsurface scattering tends to be more noticeable on a smaller object than a larger one, according to our observation.

In this paper, we propose a novel technique to estimate the scattering parameter from photographs of several translucent spheres of varying radii. Since the sphere image provide various normal directions, it is reasonable to analyze the spheres of translucent materials. Furthermore, we are able to synthesize realistic computer graphics of translucent objects according to the estimated parameters.

II. Previous Work

Contrary to the opaque materials, incident light to a translucent object goes into the surface and scatters inside the object. This effect is known as subsurface scattering. Subsurface scattering is categorized as single scattering [1], [2] or multiple scattering [3]. In this study, we focus on multiple scattering effect which is dominant in optically thick translucent materials such as waxes and soaps.

Investigation of the scattering parameter is an inverse problem of the photo-realistic rendering of translucent materials. Several methods to synthesize translucent materials have been proposed topic for a decade. The photon mapping [4] is the method of synthesize translucent materials accurately. However, it requires a lot of cost to compute, it is difficult to acquire far estimate the scattering parameters using this model. Jensen et al. [5] developed a subsurface scattering rendering method using a dipole approximation of bidirectional scattering surface reflectance distribution function (BSSRDF), and the expansion for multi-layer materials [8] has also been published. In these papers, they improved the speed of rendering computation significantly. Furthermore, Mukaigawa et al. [6] and Munoz et al. [7] analyzed subsurface scattering according to the dipole approximation. Nevertheless, the dipole approximation assumes that the object surface is infinite flat plane. According to our observation, the effect of subsurface scattering becomes more noticeable on a curved surface of smaller sphere. Texture-space diffusion technique [9] is faster approximation of subsurface scattering. This uses Gauss filtering, then diffuse light blur the irradiance map in texture-space, it means, the

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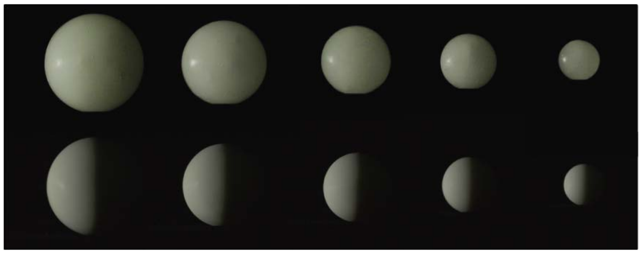
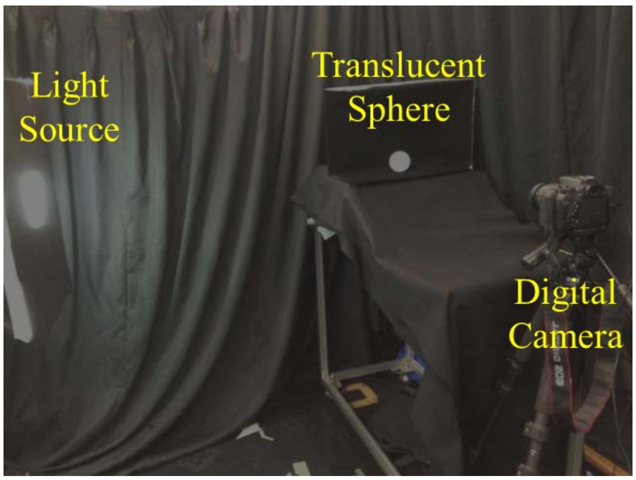
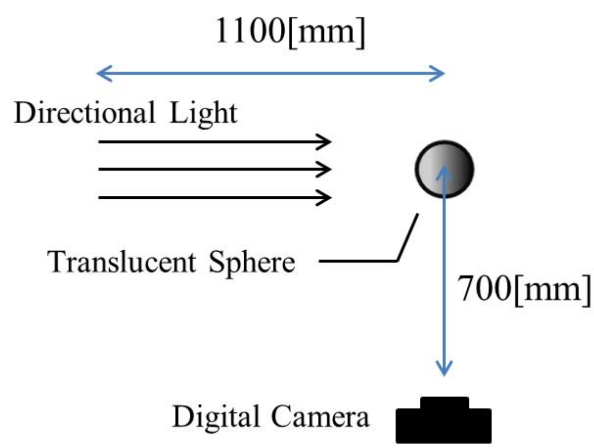


Figure 2. Photograph that we acquire from real translucent spheres of varying radii made of wax (top) and soap (bottom).



(a) photo



(b) illustration

Figure 3. Experiment environment.

calculation cost and the size of the required memory is the problem applying to estimation of the scattering parameter.

III. Our Approach

To obtain the scattering parameters by revealing the relation between the radius of the translucent sphere and translucency, we employ curvature-dependent reflectance function which represents the effect of subsurface scattering depending on the curvature. First, we take photographs of spheres of multiple radius under controlled light condition. Obtaining the appropriate scattering properties from a real object, we realize real-time rendering of translucent materials from measured CDRF. In the following sections, we describe the method to require the measured CDRF.

A. BSSRDF Approximatoin by Curvature-Dependent Reflectance Function

In this paper, we employ "Curvature-Dependent Reflectance Function (CDRF)" [10] which is an approximation of BSSRDF for translucent materials. CDRF enables us to synthesize the appearance of translucent materials in real-time. Contrary to the dipole approximation [5] which relies on the flat surface assumption, CDRF takes into account of the subsurface scattering effect on a curved surface.

The surface with curvature κ can be approximated locally by that of the sphere, radius $r = 1/\kappa$. The irradiance of the sphere is determined with the cosine term of incident angle θ_i.

On an opaque sphere, the radiance on the area where $\theta_i > \pi/2$ is perfectly dark because it is not irradiated directly. Instead, on a translucent sphere, the area is slightly bright due to the subsurface scattering effect from the directly illuminated area.

In accordance with the previous work [10], CDRF $f_r^c(\theta_i, \kappa)$ is represented by a convolution of the irradiance $E(\theta_i)$ and Gauss function $g(\theta_i, \sigma)$ to provide blurring effect.

$$f_r^c(\theta_i, \kappa) = (E * g)(\theta_i) \tag{1}$$

$$E(\theta_i) = \max(\cos\theta_i, 0) \tag{2}$$

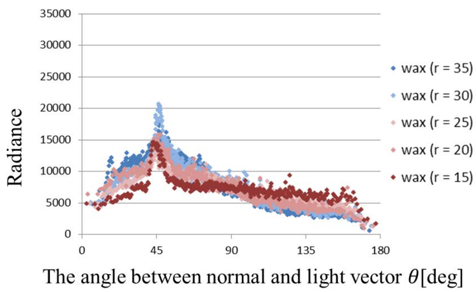
$$g(\theta_i, \sigma) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{\theta_i^2}{2\sigma^2}\right) \tag{3}$$

Accordingly, observing on the θ_i axis, σ is supposed to be, relatively, in inverse proportion to the radius r. Therefore, assuming that $\sigma(\kappa) = \sigma_0/r = \sigma_0\kappa$. σ_0 corresponds to the scattering intensity.

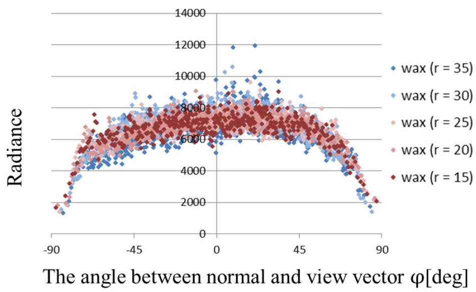
B. Experiment Environment

Since CDRF is the efficient method in the field of computer graphics, since fast approximation of subsurface scattering, thus we decide to obtain measured-CDRF from real object to synthesize realistic translucent object in real-time.

To obtain the relationship between curvature and the subsurface scattering effect, we prepare several spheres of different radii made of translucent materials. In this paper, we prepare five different radius(35, 30, 25, 20, and 15[mm]) of spheres made of two different translucent materials, such as wax and soap. Figure 3 shows experiment environment that we prepared. First, we irradiate a directional light to the



(a)



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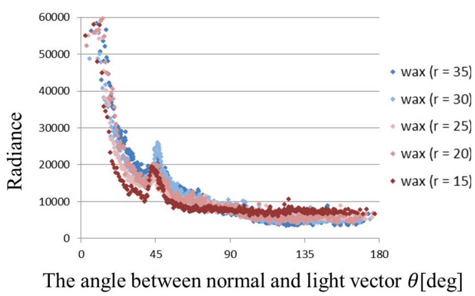
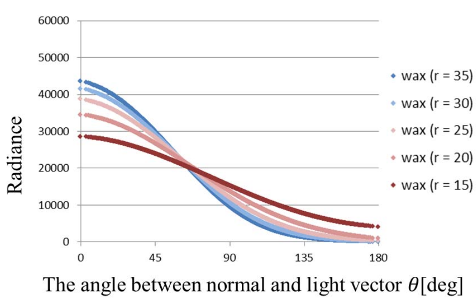


(c)



(d)

Figure 4. Radiance acquired from photograph of spheres made of wax. (a) and (b) show the correlation between radiance and , and the correlation between radiance and , respectively. The correlation between radiance and which is removed the effect of Fresnel transmission in (c). The result of the fitting to CDRF in (d)

sphere from the left, then we take a single photograph for each sphere. The distance between light source and sphere, and between digital camera and the center of sphere are 1100 [mm] and 700 [mm], respectively. Since these have enough distance, we assume that the light source to be directional light, and a camera view to be orthographic projection.

From each photograph, we obtain the correlation between curvature and translucency. To obstruct the environmental light, we conduct our experiments in a darkroom. In addition, to obtain the quantity of the scattering light energy, we use a digital camera with a linear radiometric response function.

C. Acquiring CDRF from Real Object

Figure 2 shows the photograph of the translucent spheres with varying radii, upper spheres are made of wax, and lower ones are made of soap. Spheres are aligned from left to right in decreasing order of size. The directional light irradiates the spheres from the left side.

Analyzing the shading of translucent spheres, the effect of transmitted light can also be measured in the area not directly irradiated by light. Furthermore, it can also be measured that the effect of subsurface scattering tends to be more noticeable on smaller sphere. In addition, spheres made of soap are optically thicker than those made of wax. From these images, for each radius and each materials, we acquire the correlation between radiance and θ: the angle between the normal vector and light vector over the sphere. Similarly, we acquire the correlation between radiance and φ: the angle between the normal and view vector. Fig. 4-(a) and (b) show the data we acquired from photograph of spheres made of wax. It appears that the peak of radiance around 45[deg] results from the specular light on the material surface. From these data, the radiance on the area where $\varphi > \pi/2$ tend to be darker than the radiance that is defined by CDRF. We assume that it is because the feature of diffuse surface is not indicated in translucent materials. These data could contain errors based on Fresnel transmission of emitting light, namely the correlation between radiance and φ(Fig. 4-(b)) involves Fresnel's equations for reflection and refraction. To approximate the effect of subsurface scattering with CDRF accurately, we recalculate the radiance by removing the effect of Fresnel transmission as shown in Fig. 4-(c). Because of this, measured CDRF becomes more consistent with conventional CDRF method.

Finally, we acquire σ: the scattering intensity from the correlation between curvature and translucency. As a result of applying least squares method to the whole plot of the data, σ of wax and soap are 20.23 and 14.15 respectively. Figure 4-(d) shows the radiance which we approximate radiance acquired with CDRF. As above, we obtain the correlation between curvature and translucency from real objects.

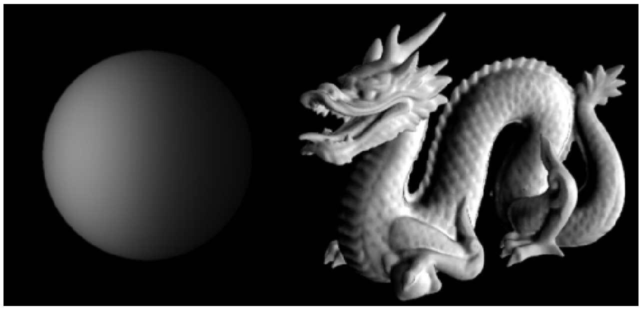


Figure 5. Synthesized translucent sphere(left) and Dragon(right) with measured CDRF

D. Rendering using Measured CDRF

Consequently, we apply the measured CDRF to 3D objects. To synthesize 3D objects in real-time, we store measured CDRF into a look-up-table. Figure 5 shows the synthesized translucent sphere(left) and Dragon(right) with measured CDRF respectively. We refer to the look-up-table using input curvature and σ. Moreover, we revise the radiance corresponding to φ (the angle between the view vector and normal vector) of a drawing point. Results show that our method succeeds in rendering realistic translucent materials and synthesizing a soft shade by the influence of Fresnel transmission.

IV. Conclusion and Discussion

In this paper, we propose a method to acquire a scattering parameter from a photograph of real translucent spheres. We approximate the effect of subsurface scattering according to the curvature, it enables us to estimate the scattering parameter from variety radius of spheres. However, it is not always possible to prepare several radius of spheres of the target translucent material. Therefore, to obtain the scattering parameters from arbitrary shape object is our future work.

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