Which BSSRDF model is better for Heterogeneous Materials?

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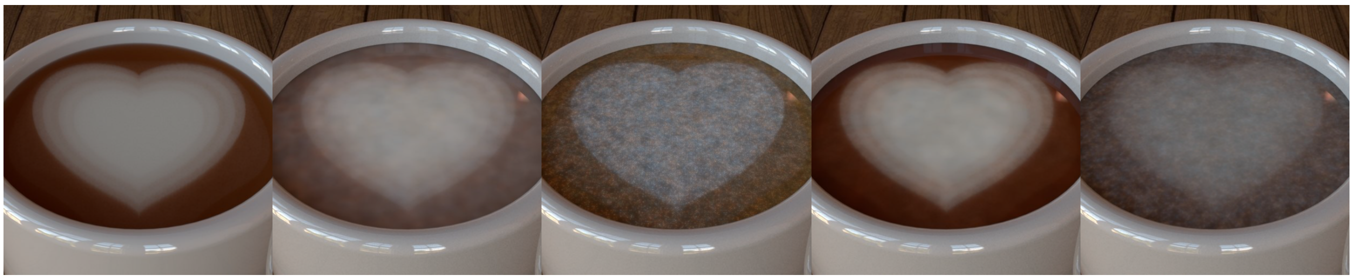

(a) (b) (c) (d) (e)

Figure 1: Results of rendering heterogeneous materials. image (a) is rendered by path tracing. Other images are rendered by the method of Sone et al. [Sone et al. 2017] combined with (b): the dipole model [Jensen et al. 2001], (c): the quantized diffusion [D'Eon and Irving 2011], (d): the better dipole model [D'Eon 2012], and (e): the directional dipole model [Frisvad et al. 2014] for subsurface scattering. All images ignore single scattering.

ABSTRACT

We present an improved method for rendering heterogeneous translucent materials with existing BSSRDF models. In the general BSSRDF models, the optical properties of the target object are constant. Sone et al. have proposed a method to combine with existing BSSRDF models for rendering heterogeneous materials. However, the method generates more bright and blurred images compared with correctly simulated images. We have experimented with various BSSRDF models by the method and rendered heterogeneous materials. As a result, the rendered image with the better dipole model is the closest to the result of Monte carlo simulation. If incorporating the better dipole model into the method proposed by Sone et al., we can render more realistic images of heterogeneous materials.

CCS CONCEPTS

• **Computing methodologies → Rendering**; *Ray tracing*;

KEYWORDS

subsurface scattering, participating media, BSSRDF, translucent materials

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1 INTRODUCTION

In recent years, several *bidirectional scattering surface reflectance distribution function* (BSSRDF) models are proposed. BSSRDF models can efficiently approximate subsurface scattering in translucent materials. If we want to use general BSSRDF models to simulate scattering events in materials, we need to suppose that optical properties of materials are constant. However, many of real world translucent materials are heterogeneous, and there are no versatile BSSRDF models for rendering these materials. Sone et al. have proposed a method for approximating light scattering events in heterogeneous materials using existing BSSRDF models [Sone et al. 2017]. The method generates more bright and blurred images compared with correctly simulated images.

We focus on existing BSSRDF models applied to the method of Sone et al. to improve rendered images. Sone et al. use the dipole model [Jensen et al. 2001] which is a pioneer BSSRDF model for subsurface scattering. After the dipole model was appeared, more efficient BSSRDF models are proposed. We think that if more efficient BSSRDF model is combined with the method, rendering results of heterogeneous materials may improve In order to try this idea, we apply several BSSRDF models to the method and render heterogeneous translucent materials.

2 OUR APPROACH

We render homogeneous materials and compare to the result of Monte carlo simulation to find out characteristics of existing BSSRDF models. The BSSRDF models are the dipole model [Jensen et al. 2001], the quantized diffusion model [D'Eon and Irving 2011], the better dipole model [D'Eon 2012], and the directional dipole model [Frisvad et al. 2014]. It is only take into account multiple scattering and ignore single scattering in this experiment. We compute root mean squared error (RMSE) of images by using each BSSRDF model when a path traced image is ground truth.

We render heterogeneous materials with the method [Sone et al. 2017] and existing BSSRDF models and compare brightness of rendered materials with a path traced result. The method consider a material of neighborhood area of incident and exitant points of light ray as homogeneous by averaging optical properties (scattering coefficient; σ_s and absorption coefficient; σ_a) in the area. This area is the inside of the ellipse, and long axis of the ellipse is a line segment connecting incident and exitant points of a ray. Averaged properties can assign to diffuse reflectance function of existing BSSRDF models. After modified BSSRDF models, we compute radiance of ray like rendering homogeneous materials. Then we render heterogeneous materials in this procedure, and compare with a path traced image. Also In this experiment, we only consider multiple scattering.

3 RESULTS

Table 1 shows root mean squared error (RMSE) with results of rendering homogeneous materials using BSSRDF models [D'Eon 2012; D'Eon and Irving 2011; Frisvad et al. 2014; Jensen et al. 2001] and an image of path tracing. RMSEs of the dipole model [Jensen et al. 2001] and the better dipole model [D'Eon 2012] are smaller in highly scattering medium. On the other hand, the directional dipole model [Frisvad et al. 2014] and the quantized diffusion [D'Eon and Irving 2011] have slightly smaller RMSE.

Table 1: RMSEs of rendered images by using existing BSSRDF models.

BSSRDF model	$\sigma_s = 0.99, \sigma_a = 0.01$	$\sigma_s = 0.79, \sigma_a = 0.21$
dipole	34.42	92.72
quantized diffusion	79.58	87.46
better dipole	34.36	91.57
directional dipole	95.92	87.42

We render heterogeneous material by the method [Sone et al. 2017] and existing BSSRDF models [D'Eon 2012; D'Eon and Irving 2011; Frisvad et al. 2014; Jensen et al. 2001]. In the rendered scene, we have a cube arranged two materials to make checkerboard patterns. Material A is a strongly scattered medium and has a white color. Another material B is a more absorption medium than material A and has a gray color. It is lit vertically on only one side of the cube with directional light. When we compare with image of this scene in each materials, images by using the quantized diffusion [D'Eon and Irving 2011] and the directional dipole model [Frisvad et al. 2014] are very dark on material A. For that reason, these images looke like it is unified in gray as a whole. On the other hand, the images by using the dipole model [Jensen et al. 2001] is bright on material B. Looking at all rendering images, the image by using the better dipole model [D'Eon 2012] is the more similar appearance to the path traced image than others.

In the image of checkerboard cube, we compute the brightness of the images by using BSSRDF models when It is compared with the image of path tracing. Table 2 shows results of brightness ratio of images by using BSSRDF models when values of each pixels in path traced image is 1.0. Brightness ratio of using the dipole model [Jensen et al. 2001] and the better dipole model [D'Eon 2012] is larger than brightness of image of path tracing in both materials. Particularly when using the dipole model, it is more than twice as bright as part of material B. Brightness of using the quantized diffusion [D'Eon and Irving 2011] and the directional dipole model [Frisvad et al. 2014] is darker in the material A and brighter in the material B than Brightness of path traced image.

Table 2: Brightness ratio of images by using BSSRDF models comparison with the image of path tracing.

	material A[1]		materials B[2]	
BSSRDF model	range	average	range	average
dipole	1.2 ~1.8	1.45	1.8 ~2.4	2.08
quantized diffusion	0.5 ~1.2	0.931	1.4 ~2.4	1.84
better dipole	1.3 ~1.8	1.401	1.0 ~1.4	1.29
directional dipole	0.3 ~1.0	0.794	1.0 ~1.8	1.35

[1] $\sigma_s = 0.899 \sim 0.998, \sigma_a = 0.002 \sim 0.101$
[2] $\sigma_s = 0.699 \sim 0.798, \sigma_a = 0.202 \sim 0.301$

In Figure 1, we render heterogeneous materials, latte art. If making a comparison between image of path tracing (image (a)) and image of using BSSRDF models, The image using the method of Sone et al. and the better dipole model [D'Eon 2012] (image (d)) is the most similar than other images. In the part of milk, images by using the quantized diffusion [D'Eon and Irving 2011] and the directional dipole model [Frisvad et al. 2014] are darker. In the part of coffee, it blur white in image by using the dipole model [Jensen et al. 2001], and it dilute brown in image by using directional dipole model. As a result, when rendering heterogeneous materials realistically using existing BSSRDF models, better results can be generated by combining the method of Sone et al. with the better dipole.

4 CONCLUSIONS AND FUTURE WORK

We combine existing BSSRDF models [D'Eon 2012; D'Eon and Irving 2011; Frisvad et al. 2014; Jensen et al. 2001] into the method proposed by Sone et al. [Sone et al. 2017] to improve results of the method. Consequently, we find that combining of the better dipole model [D'Eon 2012] with the method of Sone et al. is a good result. While testing several BSSRDF models, we also find rendered images look different depending on each model. In the future, We will further improve the method for rendering heterogeneous materials with BSSRDF models realistically.

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