A practical model for computing the BRDF of real world materials

Ke Chen* Charly Collin Ajit Hakke-Patil Sumanta Pattanaik†
University of Central Florida

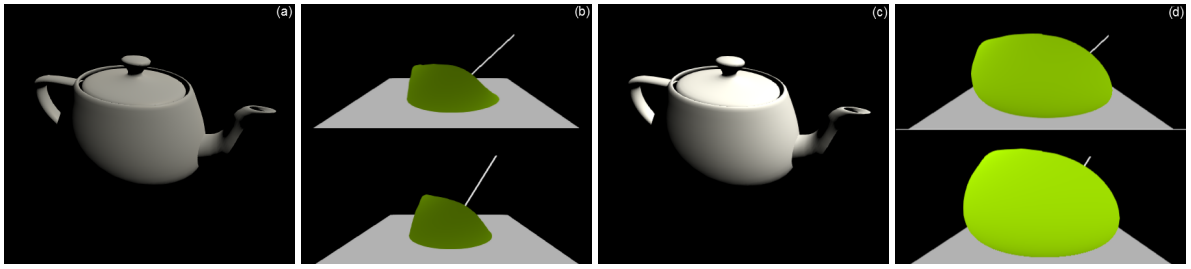

Figure 1: *Rendering of materials composed of titanium dioxide particles (effective radius 0.4 and variance 0.3 for power law size distribution) embedded in a transparent binder. (a) Shows the result using single scattering approximation(SSA)+Diffusion approximation and (b) BRDF lobes for two different incident angles. (c) and (d) Show the rendering and BRDF lobes using proposed Ambartsumian's integral equation.*

1 Introduction

Accurately modeling BRDF for real world materials is important and challenging for realistic image synthesis. For a majority of materials most of the incident light enters the material, undergoes multiple scattering under the surface before exiting the material's surface as reflection. Physically correct modeling of such BRDF must take into account of this subsurface volumetric light transport. Most of the accurate numerical solution methods (ex: Monte Carlo, Discrete Ordinate Methods (DOM)) for volumetric light transport compute radiance field for the whole volume, and are expensive. As BRDF ultimately relates only the outgoing radiation field at the boundary to the incident radiation, radiation field computed for the bulk of the material does not provide any useful information and hence the effort involved in computing them can be considered as wasteful. So for efficient BRDF computation any method that allows us to compute the radiance field only at the boundary would be a preferable choice. The search for such a method led us to the Ambartsumian's method [Sobolev 1975; Mishchenko et al. 1999]. This method models the exiting light field from the surface of a semi-infinite material layer in the form of integral equations, and hence allows us to model the BRDF from such surfaces as a set of integral equations as given below:

$$\begin{aligned} R^m(\eta,\eta_o) = \frac{\alpha}{4(\eta+\eta_o)}\Big[& p^m(-\eta,\eta_o) \\ & + 2\eta_o \int_0^1 p^m(\eta,\eta')R^m(\eta',\eta_o)\mathrm{d}\eta' \\ & + 2\eta \int_0^1 p^m(\eta',\eta_o)R^m(\eta,\eta')\mathrm{d}\eta' \\ & + 4\eta\eta_o \int_0^1 R^m(\eta,\eta')\mathrm{d}\eta' \int_0^1 p^m(\eta',-\eta'')R^m(\eta'',\eta_o)\mathrm{d}\eta''\Big] \end{aligned} \tag{1}$$

Here the R^m and p^m represent the m^{th} order Fourier expansion coefficients of the reflectance function and the phase function respectively. α is the single scattering albedo. η stands for the cosine value of the scattering zenith angle, and η_o for the cosine value of the incident light beam. Given single scattering albedo and the Fourier coefficients of the phase function of the subsurface material, these integral equations can be numerically solved to compute the coefficients for the BRDF and in turn to compute the reconstructed BRDF.

*e-mail:chenke6950@knights.ucf.edu
†e-mail:sumant@cs.ucf.edu

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2 Implementation and Results

Two input parameters are needed to solve equation 1 for each R^m. They are: the single scattering albedo α and the phase function. The single scattering albedo and the phase function for layered materials composed of pigments embedded in a medium can be computed using Lorenz-Mie theory. The integral equation can be solved iteratively by standard numerical approach.

Figure 1 shows a comparison of our model with BRDF model using diffusion approximation [Jensen et al. 2001]. In Figure 2 we show the validation of our results with DOM solution. In supplementary material, we show renderings using BRDF generated with different pigment parameters. The computation of the initial parameters and the iterative solution of Ambartsumian integral equation takes only a few seconds in our system implemented in C++ and OpenCL running on an Intel i7-3960X processor and a NVIDIA GTX 580 graphics card. So it is fast enough for interactive material design.

In the future, we would like to extend this model to take into account finite and multi-layered materials.

Figure 2: *A BRDF lobe for* 36.8^o *incident angle, computed using a standard DOM implementation (left) and using our method (right).*

References

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