DreamWorks Fabric Shading Model: from Artist Friendly to Physically Plausible

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Figure 1: Different fabric materials under the same environment lighting

CCS CONCEPTS

• **Computing methodologies → Rendering**; **Reflectance modeling**;

KEYWORDS

Cloth rendering, importance sampling, anisotropic BRDF

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1 INTRODUCTION

Since Shrek 2, DreamWorks artists have used the fabric model developed by [Glumac and Doepp 2004] extensively on cloth material shading. Even after we developed the physically based microcylinderical cloth model by [Sadeghi et al. 2013], they continued to prefer the intuitive control of the DreamWorks fabric shading model, which is also a cyindrical shading model, with easy to use artistic controls for highlights, and highlight directions.

In this talk, we present our approach to make this much-loved, production-oriented fabric shading model physically plausible, so we can use it within the framework of a physically based renderer that requires its $brdf$ models to be energy conserving and, ideally, reciprocal as well. We also present an accurate importance sampling algorithm for this fabric shading model that makes it efficient to render within a path tracer. Figure 1 shows five different dress looks we created using our fabric material.

2 BRDF

As described in [Glumac and Doepp 2004], DreamWorks fabric shading model considers the class of fabrics composed of cylindrical, dielectric fibers that are woven together. We assume that the fibers themselves are not visible, choosing instead to model the light response as aggregate light reflected from a small patch of fibers. [Marschner et al. 2003] showed that light incident on a dielectric cylinder is reflected in a specular *cone* along the mirror vector with respect to the tangent. Our $brdf$ models this specular cone with the following equation:

$$S(\theta_i, \phi_i, \theta_o, \phi_o) = (1 - |\sin\theta_h|)^n$$

where $\theta_h = (\theta_o + \theta_i)/2$, and θ is the angle with respect to the normal plane.

2.1 Energy Conservation

In order for it to be physically plausible, we need to ensure that our fabric model is energy conserving. We compute the normalization factor for our $brdf$ by integrating the $brdf$ over the outgoing hemisphere for a maximally reflective incident vector. For a cylindrical fiber, the maximally reflective incident vector will always be located in the normal plane. This leads to $\theta_i = 0$, which leads to $\theta_h = \theta_o/2$. The normalization integral over the entire outgoing hemisphere is

$$I_o = \int_\Omega (1 - |\sin\theta_\mathrm{h}|)^\mathrm{n}\,\mathrm{d}\omega_o$$

This integral can be evaluated using a combination of binomial expansion and a recursive formulation for the integral of an exponential sinusoide. The final expression which can be evaluated analytically for any given exponent, comes out to be:

$$I_o = 4\pi \sum_{k=0}^{n} \binom{n}{k} (-1)^k \left(\int_0^{\frac{\pi}{4}} \sin^{\mathrm{k}} \theta_{\mathrm{h}} \, \mathrm{d}\theta_h - 2 \int_0^{\frac{\pi}{4}} \sin^{\mathrm{k}+2} \theta_{\mathrm{h}} \, \mathrm{d}\theta_h \right)$$

The reciprocal of I_o, $\frac{1}{I_o}$, is the normalization factor for the $brdf$. In practice, we precompute the normalization factors for a predetermined range of exponents. In our tests, a range of 0 to 30 for the exponent was more than sufficient to express the spectrum of fabrics required in our workflow. To allow for intuitive user control, we expose a fabric roughness α parameter that is internally converted to exponent n using the following equation:

$$n = ceil(1 + 29.0 * (1 - \alpha) * (1 - \alpha))$$

Figure 2 shows the results of white furnace tests, where we see total reflected energy increases with roughness for unnormalized fabric $brdf$, while normalized fabric $brdf$ test results show consistent reflected energy across all roughness values.

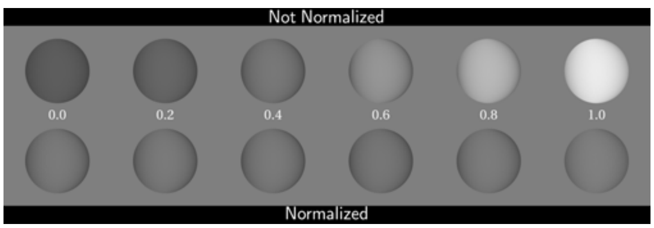

Figure 2: Furnace tests of the fabric model with roughness α ranging from 0.2 to 1, before and after normalization

2.2 Sampling

To sample the fabric $brdf$ efficiently, we first select θ_h based on the following PDF:

$$p(\theta_h) = \frac{n+1}{\pi}(1 - \sin\theta_h)^n$$

This PDF can be accurately sampled using:

$$\theta_h = \sin^{-1}(1 - \xi^{n+1})$$

We then convert θ_h to θ_i, using $\theta_i = 2\theta_h - \theta_o$ to compute the sample direction. Additionally, we divide the PDF of θ_h by the Jacobian of the inversion to compute the PDF of θ_i:

$$p(\theta_i) = p(\theta_h). \frac{\mathrm{d}\omega_h}{\mathrm{d}\omega_i}$$

Finally, in [Walter et al. 2007], the Jacobian to convert the sampling from half vector to the incident vector was shown to be: $\frac{\mathrm{d}\omega_h}{\mathrm{d}\omega_i} = \frac{1}{4(\omega_i.\omega_h)}$, so the PDF of θ_i is:

$$p(\theta_i) = \frac{n+1}{\pi}(1 - \sin\theta_h)^n * \frac{1}{4(\omega_i.\omega_h)}$$

Our sampling algorithm is highly efficient because it is based on the exact inversion of the analytical integral of the pdf. Figure 3 shows a simple cylinder rendered with our fabric material model with low roughness; in this case, using uniform sampling requires 6x to 8x number of samples to converge to a clean render compare to using our importance sampling algorithm; so using our importance sampling algorithm translates to nearly 8x speed up in a path tracer.

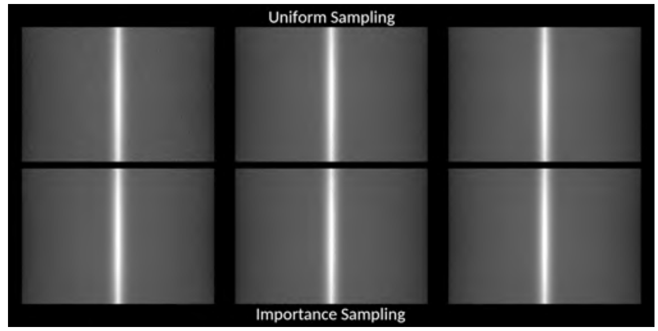

Figure 3: Uniform vs Importance Sampling of Fabric $brdf$

2.3 Results

By examining the mathematical characteristics of an empirical fabric shading model, we developed an artist-friendly and physically plausible fabric $brdf$, with efficient closed-form formulations for computing its normalization factor for energy conservation and for importance sampling the $brdf$. Figure 4 shows a variety of cloth appearances ranging from silk to velvet created with our fabric $brdf$ under the same enviroment lighting, with two raytraced bounces.

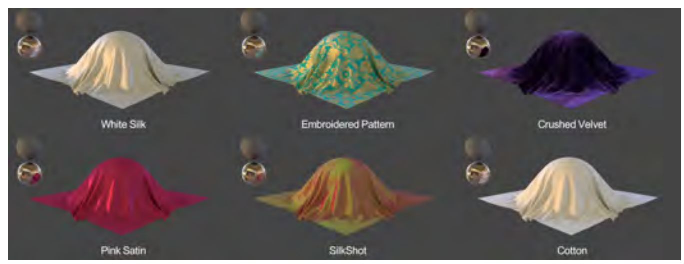

Figure 4: A variety of fabric appearances achieved using artist specified inputs for fabric thread direction, orientation, roughness and color. Note the illumination setup is the same.

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