Addressing Grazing Angle Reflections in Phong Models

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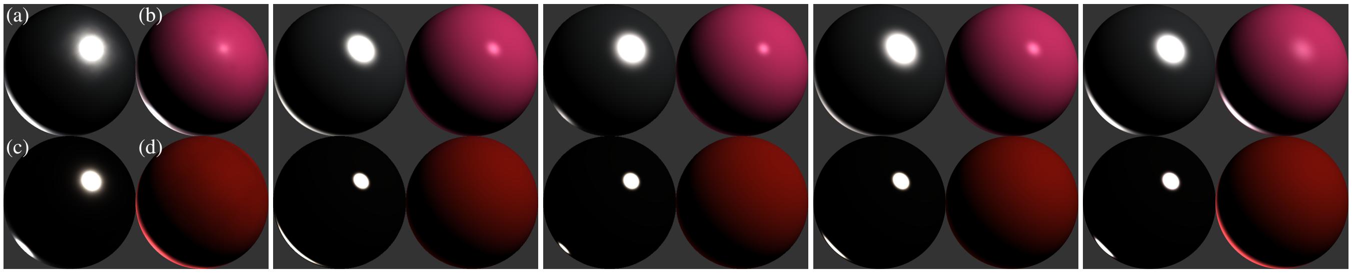

Measured [Matusik et al. 2003]   Phong (1)   Blinn-Phong (2)   Our Phong variant (3)   Ours w. Fresnel

Figure 1: *Measured and fitted BRDFs of the materials: (a) two-layer-silver, (b) violet-rubber, (c) nickel, and (d) red-fabric2. We illuminate the rendered spheres by a directional light at glancing incidence (NE hemisphere) and one at grazing incidence (SW hemisphere). Our new Phong model variant is a combination of the Phong and Blinn-Phong variants, which achieves a better fit of the measured BRDFs at grazing angles. Note that the reflectance at grazing angles is Phong-like for some materials (a) and Blinn-Phong-like for others (c).*

The Phong illumination model is used extensively as it is simple with few parameters. It is however often challenging to fit such a single lobed model to the bidirectional reflectance distribution function (BRDF) of a real material, especially at grazing angles (Fig. 1). The fitting issues are in shortcomings of the model, in choosing error function, and in initial guess sensitivity [Matusik et al. 2003]. In previous work [Ngan et al. 2005], these issues were bypassed by using two specular lobes, by ignoring very grazing angles ($>80^\circ$), and, in cases of unsatisfactory fitting quality, by manually restarting the fitting procedure with a different initial guess. In this work, we also fit Phong models to the BRDFs measured by Matusik et al. [2003], but we focus on the difficult grazing angles. Our result is a new Phong variant that fits better to a broader range of materials, and, for this model, we address the above-mentioned fitting issues.

Common Phong Model Variants. Our model is a mixture of the modified Phong model (f_r^{P}) and the modified Blinn-Phong model (f_r^{BP}). These are defined by [Akenine-Möller et al. 2008]

$$f_r^{\mathrm{P}}(\vec{\omega}_i, \vec{\omega}_o) = \frac{\rho_d}{\pi} + \rho_s \frac{s+2}{2\pi}(\vec{\omega}_r \cdot \vec{\omega}_o)^s \qquad (1)$$

$$f_r^{\mathrm{BP}}(\vec{\omega}_i, \vec{\omega}_o) = \frac{\rho_d}{\pi} + \rho_s \frac{s+8}{8\pi}(\vec{\omega}_h \cdot \vec{n})^s \ , \qquad (2)$$

where ρ_d and ρ_s are diffuse and specular reflectance parameters and s is a shininess parameter, $\vec{\omega}_i$ is the direction toward the light source, $\vec{\omega}_o$ is the direction toward the viewer, $\vec{\omega}_r = 2(\vec{\omega}_i \cdot \vec{n})\vec{n} - \vec{\omega}_i$ is the direction of the light reflected perfectly around the surface normal $\vec{n}$, and $\vec{\omega}_h = (\vec{\omega}_i + \vec{\omega}_o)/|\vec{\omega}_i + \vec{\omega}_o|$ is the half-vector. The specular highlights produced by the two variants (1–2) are different, especially at grazing angles (Fig. 1).

Comparison to Measured BRDFs. When we fit the Phong models (1–2) to measured BRDFs using nonlinear optimization, we find examples where the Blinn-Phong variant (2) has the smallest error (Fig. 1c), but also examples where the Phong variant (1) has the smallest error (Fig. 1a). While the Blinn-Phong-like reflectance is probably due to surface microfacets [Ngan et al. 2005], we believe that the Phong-like reflectance is probably due to subsurface scattering. Thus, although the modified Phong model in theory might seem physically inappropriate, it does seem to mimic the grazing angle reflectance of some real materials.

As in previous work [Ngan et al. 2005], we observe that it is important to multiply the specular reflectance ρ_s by the Fresnel reflectance $R_F(\vec{\omega}_i \cdot \vec{\omega}_h, \eta)$ [Akenine-Möller et al. 2008], where η is the refractive index of the material. This is necessary to model the effect that the reflectance in general is significantly stronger at grazing angles than at glancing angles (Fig. 1).

Our Phong Model Variant. The existence of both Phong-like, Blinn-Phong-like, and mixed reflectance behaviour in real-world materials suggests that a combination could be useful. We thus propose a model with interpolation of the two different cosines:

$$f_r^{\mathrm{new}}(\vec{\omega}_i, \vec{\omega}_o) = \frac{\rho_d}{\pi} + k_s\big((1-\alpha)(\vec{\omega}_r \cdot \vec{\omega}_o) + \alpha(\vec{\omega}_h \cdot \vec{n})^4\big)^s \ , \qquad (3)$$

where $\alpha \in [0, 1]$ is the interpolation parameter. For simplicity, the specular coefficient k_s replaces the specular reflectance ρ_s multiplied by the energy conservation term $\frac{s+x}{x\pi}$. We multiply k_s by R_F to include Fresnel reflectance. The Blinn-Phong cosine is raised to the 4th power, as the Phong exponent is roughly 4 times stronger than the Blinn-Phong exponent [Akenine-Möller et al. 2008].

Effectively, this model enables us to control and shape the reflectance at grazing angles of incidence. We can thus approximately accommodate both grazing angle reflectance due to subsurface scattering and due to microfacets in a simple Phong model.

Fitting Results and Observations. The Euclidean norm (L^2) is not a good error function as it primarily fits the cosine lobe to the tops of the specular highlights. We solve this issue by using the L^1 norm as it roughly results in a fitting to the base of the specular highlights. Visually, we find the L^1 results more reasonable. We use consecutive optimizations to obtain a fitting procedure which is not initial guess sensitive. Our proceduce is: (i) optimize only ρ_d and k_s, (ii) optimize only s and α (and η), and (iii) optimize s, α, and k_s (and η). This gives robust convergence for all the BRDFs measured by Matusik et al. [2003]. We present four examples of such fits in Fig. 1.

References

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