Estimating Multi-layer Scattering in Faces using Direct-Indirect Separation

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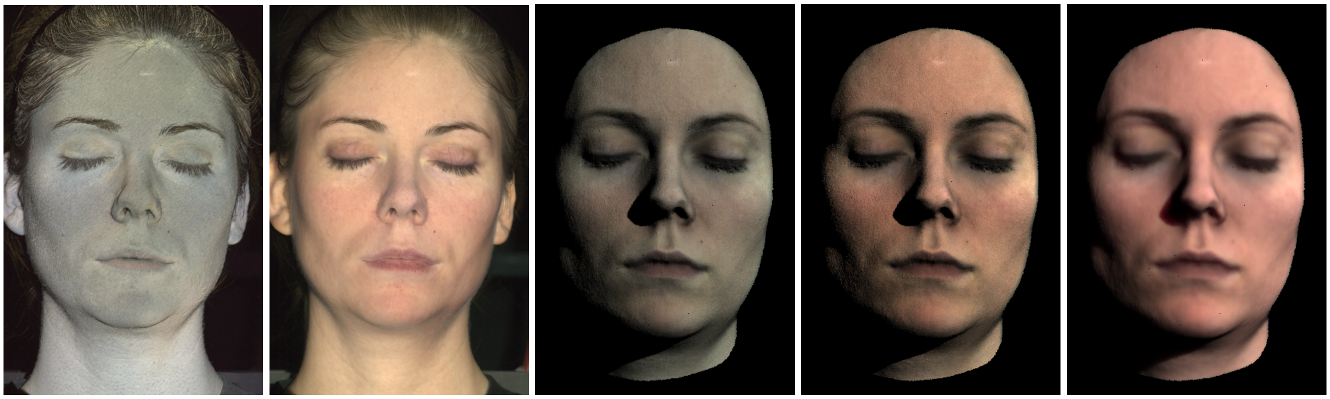

(a) Shallow scattering (b) Deep scattering (c) Reflectance R_1 (d) Transmittance T_1 (e) Reflectance R_2

Figure 1: *Direct-indirect separation of the observed diffuse reflectance of a face ((a) & (b)), and fitting of a two-layer scattering model of diffuse skin reflectance. The estimated reflectance and transmittance of the two layers are depicted under a novel lighting condition in (c)-(e).*

1 Introduction

Accurate simulation of the diffuse scattering of light in skin is important for achieving the charateristic "softness" in skin appearance and subtle effects such as light bleeding at shadow boundaries. While the dipole diffusion model has been widely used in computer graphics to efficiently simulate these effects for translucent materials, it tends to over-smooth the details near the skin surface resulting in an unnatural "waxy" appearance for faces. Donner&Jensen [2005] recently introduced a multi-layer subsurface scattering model for rendering human skin more realistically. They relate the multi-layer model to the various epidermal and dermal layers of skin and provide scattering parameters for the layers from tissue optics literature. While providing more convincing results for human skin than the dipole model, the greater complexity of the multi-layer model also makes it more challenging to fit the scattering parameters from measured data. Unlike the dipole model, it is unclear how to fit the various parameters of the multi-layer model from a typically observed scattering profile from a live subject. We seek to address this problem in this work. Our approach is to employ the recently introduced direct-indirect separation technique of Nayar et al. [2006] in order to decompose the diffuse scattering of light in skin into a shallow and a deep scattering component respectively. Given the separated components and an additionally observed scattering profile, we then estimate parameters of a simplified *two-layer* scattering model by employing the Kubelka-Munk theory to the total diffusely reflected radiance.

2 Method

Let the total diffuse reflectance of skin at any surface point be R_d, and the separated direct and indirect components be R_{direct} and $R_{indirect}$ respectively. Then $R_d = R_{direct} + R_{indirect}$.

According to the Kubelka-Munk theory of layered diffuse reflectance, if R_1 is the diffuse reflectance and T_1 is the diffuse transmittance of layer 1 and R_2 is the diffuse reflectance of layer 2, then the combined total diffuse reflectance of the two layers R_{12} is given as:

$$R_{12} = R_1 + \frac{T_1 \cdot R_2 \cdot T_1}{1 - R_2 \cdot R_1}. \quad (1)$$

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Assuming a two-layer scattering model we have $R_d = R_{12}$, which leads to $R_{direct} = R_1$, and $R_{indirect} = \frac{T_1 \cdot R_2 \cdot T_1}{1 - R_2 \cdot R_1}$. We also make the observation that the shallow scattering component exhibits significantly less scattering compared to the deep scattering component (Figure 1 (a)-(b)). Given an observed scattering profile, we fit the lower $2/3^{rds}$ of the profile (far enough from the peak to correspond only to deep scattering) to the dipole model assuming $R_{indirect}$ as the albedo. Such a fit is fairly accurate for the lower end of the scattering profile where scattering in the second layer dominates, but underestimates the true profile close to the peak where the contribution of the top layer is significant. We attribute this residual close to the peak of the profile to be the reflectance profile of layer 1 and fit a multipole model to it assuming R_1 as the albedo. We then employ the estimated parameters of the multipole fit for scattering in layer 1 in order to compute diffuse transmittance T_1 due to layer 1, and feed this back into Equation 1 in order to estimate the true diffuse reflectance R_2 of layer 2. Finally, we refine our estimate of the scattering parameters of layer 2 by employing R_2 as the albedo for the dipole fit to deep scattering.

3 Results

Our acquisition setup involves an LCD projector cross-polarized with respect to a digital still camera in order to project appropriate patterns for direct-indirect separation, as well for observing diffusion profiles over a face (the acquisition details are described in a current submission to SIGGRAPH 2008). Figure 1 presents renderings of an acquired face with the estimated scattering parameters of the shallow and deep scattering layers. We employ the multipole model for layer 1 with an assumed thickness of $0.5mm$, while approximating deep scattering with the dipole model assuming layer 2 to be infinitely thick.

References

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NAYAR, S. K., KRISHNAN, G., GROSSBERG, M. D., AND RASKAR, R. 2006. Fast separation of direct and global components of a scene using high frequency illumination. *ACM Transactions on Graphics 25*, 3 (July), 935–944.