Estimating Diffusion Parameters From Polarized Spherical Gradient Illumination

Introduction

The appearance of many common materials is the result of subsurface light transport that gives rise to the characteristic “soft” appearance and the unique coloring of such materials. Jensen et al. [2001] introduced the dipole-diffusion approximation to efficiently model isotropic subsurface light transport. The scattering parameters needed to drive the dipole-diffusion approximation are typically estimated by illuminating a homogeneous surface patch with a collimated beam of light, or in the case of spatially varying translucent materials with a dense set of structured light patterns. A disadvantage of most existing techniques is that acquisition time is traded off with spatial density of the scattering parameters.

Recently, Ma et al. [2007] proposed a technique to obtain high quality estimates of diffuse and specular albedo and photometric normal maps from just eight photographs under four different polarized spherical gradient lighting conditions. In addition, Ma et al. also proposed a hybrid normal rendering technique that approximates the soft appearance of subsurface scattering with local shading using measured RGB diffuse normals. This suggests a connection between spherical gradient illumination and subsurface scattering. In this work, we aim to formalize this apparent connection based on radiative transfer theory. In particular, we show that dense per-surface-point scattering parameters can be directly obtained from observations under spherical gradient illumination (Fig. 1), without resorting to any explicit fitting of observed scattering profiles.

Background

Light transport in highly scattering translucent materials can be well approximated by diffusion theory [Jensen et al. 2001]. According to radiative transfer theory, diffusion can be accurately approximated by a two-term spherical harmonic expansion of radiance:

\[ L(x, \omega) = \frac{1}{4\pi} \phi(x) + \frac{3}{4\pi} \cdot \vec{E}(x) \]  

(1)

where \( \phi(x) = \int_{4\pi} L(x, \omega) d\omega \) is the scalar fluence and \( \vec{E}(x) = \int_{4\pi} L(x, \omega) \vec{\omega} d\omega \) is the vector irradiance.

Substituting Equation 1 in the radiative transfer equation and assuming semi-infinite material, leads to the well-known diffuse BSSRDF [Jensen et al. 2001]:

\[ R_d(r) = -D \frac{\vec{n} \cdot \nabla \phi(x_0)}{d\phi(x_0)/dx} \]  

(2)

where \( r = |x_0 - x_i| \), and \( D = 1/3\sigma' \) is the diffusion constant.

Relating Equations (1) and (2) yields a mechanism for estimating scattering parameters of dipole diffusion from observations of the 1st-order spherical gradients. Specifically, Equation 2 relates the observed diffuse albedo \( R_d \) (cross-polarized 0th-order spherical statistics) to the normal aligned spherical gradient (cross-polarized 1st-order spherical statistics [Ma et al. 2007]) via the diffusion constant \( D \). Assuming that the surface normal is along the +Z direction, this leads to the following compact relation between the diffusion constant and polarized spherical gradients:

\[ D \propto \frac{R_d}{G_z} \]  

(3)

where \( G_z \) refers to the spherical gradient along the surface normal direction. Given the spherical gradients form a rotational basis, we can create a linear gradient in any arbitrary direction using a linear combination of the three principal gradients \( G_x, G_y, \) and \( G_z \).

We have empirically derived a relation that approximates the diffusion constant \( D \) using observations under spherical gradient illumination. This involves converting Equation 2, which expresses a spatial gradient, into an angular gradient by including an estimate of the local curvature \( K \) in Equation 3. In our work, we estimate the local curvature from photometric normals estimated using spherical gradient illumination.

Results

\[ \text{diffuse albedo} \quad \text{translucency \( l_t \)} \quad \text{absorption \( \sigma_a \)} \quad \text{rendering} \]

Figure 1: Per-surface point diffusion parameters estimated from just four observations under cross-polarized 0th and 1st order spherical gradient illumination conditions.

\[ \text{diffuse normals} \quad \text{translucency \( l_t \)} \quad \text{absorption \( \sigma_a \)} \quad \text{rendering} \]

Figure 2: Per-surface point diffusion parameters estimated for a red wax sample (top row) and a sandstone sample (bottom row).

REFERENCES
