Full-Spectral Image-Based Lighting with Skylight

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1. Introduction

Image-Based Lighting introduced by Debevec [1998] was based on tricolor image captured by a digital camera. However, full-spectral data is necessary for precise calculation of reflected color of an object. Tominaga et al. [2003] used sampled spectral power distribution (SPD) for estimating the basis functions of illuminant spectra and restored skylight spectra. Generally the number of the basis functions becomes three by just approximating the skylight scattering model as follows:

1. Ignore tertiary and higher Rayleigh scattering;
2. Ignore tertiary and higher Rayleigh out-scattering;
3. Mie scattering does not alter the SPD and only Rayleigh scattering changes the color of the light.

The skylight is based on the sky colour data. The algorithm is used in the light scattering model in atmosphere so that measurement of the SPD is not necessary. The method can be used to implement real-time environment mapping. Precise simulation of lighting with skylight enables designer to interactively design an outdoor visual environment such as architecture.

2. Method

2.1 Skylight Model

Since the image data is represented with tricolor value, the illuminant SPD is uniquely determined only when the number of the basis functions of illuminant SPD is three. Generally the number of the basis functions is infinite, but when the skylight is the light source, the number of the basis functions becomes three by just approximating the skylight scattering model as follows:

1. Ignore tertiary and higher Rayleigh scattering;
2. Ignore tertiary and higher Rayleigh out-scattering;
3. Mie scattering does not alter the SPD and only Rayleigh scattering changes the color of the light.

The reflected color of the non-fluorescent material is determined by the SPD of sky. The reflected color of the non-fluorescent material is given by

\[ R_{\text{reflect}} \times R_{\text{reflect}} = F \times \begin{pmatrix} R_{\text{reflect}} \\ G_{\text{reflect}} \\ B_{\text{reflect}} \end{pmatrix} = \begin{pmatrix} \sum_{i=1}^{3} s_i(\lambda) & \sum_{i=1}^{3} s_i(\lambda) & \sum_{i=1}^{3} s_i(\lambda) \end{pmatrix} \begin{pmatrix} R_{\text{sky}} \\ G_{\text{sky}} \\ B_{\text{sky}} \end{pmatrix} \]

where \( s_i(\lambda) \) is the spectral function of sky i, \( R_{\text{sky}}, G_{\text{sky}}, B_{\text{sky}} \) are the sky SPD functions. The method implements an environment mapping of a shader program as follows. First, calculate the color matrix from material spectral reflectance and skylight basis functions. The calculated matrices are saved as uniform variables for the fragment shader. Each matrix corresponds to each kind of spectral color. The calculation per pixel is just multiplying the matrix onto the RGB color sampled from irradiance map. The algorithm is very simple and is possible to implement other real-time method such as precomputed radiance transfer.

3. Result

3.1 Error Evaluation

To evaluate the error caused by this method, full spectral skylight scattering is simulated. The simulation of single skylight scattering is based on Nishita et al. [1993] and photon mapping is used for full-spectral calculation of multiple scattering.

Difference from the result directly calculated from the simulated skylight SPD is used as the error of the proposed method. The error was calculated for 24 kinds of spectral color (Macbeth ColorChecker Chart). The calculated error ratio is less than 0.01 in 12:00 ~ 16:00 and the error is smaller when the sun altitude is high and when the face is horizontal. You can see that tertiary and higher Rayleigh scattering affects the skylight at lower altitude.

The error caused by the proposed method and the error caused by just multiplying each RGB value were compared. When the reflectance of the material is wavelength dependent, the error is 10 to 100 times smaller than the error occurred when simply using dot product as reflected color. Figure 2 shows an example of the result.

![Fig. 2: The error of the reflected color of the horizontal surface.](image)

3.2 Rendering Result

Real-time program is designed to render 24 kinds of Lambertian surface with the proposed method. Figure 3 shows a rendering result.

The difference can be felt as a difference in the impression or of the temperature of the color. This kind of feeling is an important factor of a visual environment. Thus the proposed method is useful for simulating and evaluating outdoor visual environments.

![Fig.3: Result of the real-time program](image)

Reference

