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 spectral data of omni-directional light distribution. However, since the method is not based on physical model of the illuminant, measurement of the illuminant SPD is needed for each different scene.

This paper proposes a method for restoring SPD data from RGB image of skylight and calculating reflected color of synthetic objects lit by skylight. The algorithm is based on basis functions of skylight spectra given by 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.

Figure 1 shows the modeled scattering of the light. The combination of scattering and out-scattering (or absorption) of the light determines the SPD of sky. The skylight SPD $S(\lambda)$ is given by

$$S(\lambda)=\sum_{i=0}^{2} c_i s_i(\lambda) \quad \text{where} \quad s_i(\lambda)=\left(\frac{1}{\lambda^4}\right)^i s(\lambda) \quad (i=0,1,2)$$

where $s_i(\lambda)$ are the basis functions of the skylight and $s(\lambda)$ is the SPD of the sunlight.

The SPD function of the skylight is restored from camera RGB value using the matrix calculated from the basis functions of the skylight and spectral sensitivity of the camera.

$$S(\lambda)=\begin{bmatrix} s_0(\lambda) \\ s_1(\lambda) \\ s_2(\lambda) \end{bmatrix}^T \begin{bmatrix} \text{Transformation} \\ \text{from sky coefficient} \\ \text{to camera RGB} \end{bmatrix}^{-1} \begin{bmatrix} R_{sky} \\ G_{sky} \\ B_{sky} \end{bmatrix} = \begin{bmatrix} s_r(\lambda) \\ s_g(\lambda) \\ s_b(\lambda) \end{bmatrix}^T \begin{bmatrix} R_{sky} \\ G_{sky} \\ B_{sky} \end{bmatrix}$$

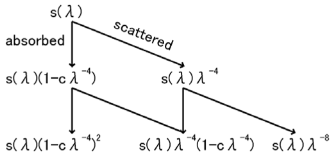

Fig. 1: SPD functions given by Rayleigh scattering.

2.2 Rendering

The reflected color of the non-fluorescent material is determined by the multiplication of the SPD of the light source and spectral reflectance of the material. RGB value of the reflected color is given by

$$\begin{bmatrix} R_{reflect} \\ G_{reflect} \\ B_{reflect} \end{bmatrix} = F \times \begin{bmatrix} 3\times 3 \text{ColorMatrix calculated from} \\ \text{Basis functions of skylight SPD} \\ \text{\& Material spectral reflectance} \end{bmatrix} \begin{bmatrix} R_{sky} \\ G_{sky} \\ B_{sky} \end{bmatrix}$$

where F is the form factor and is determined only by the geometric condition.

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 matrixes 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.

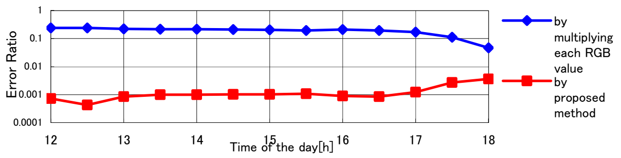

Fig. 2: The error of the reflected color of the horizontal surface.
Material: Macbeth ColorChecker Chart #1

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

Reference

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