A Real-time Rendering Method of Art Objects Based on Multi-spectral Reflection Model

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Abstract: The present study proposes a method for precise rendering of art objects under ambient light sources in a real scene. The rendering method is based on multi-spectral reflection model which developed from measuring light reflection properties on the object surface. The method consisted of a measuring part and a rendering part. In the measuring part, the object surface reflectance is measured using an imaging apparatus. The reflection properties are characterized by capturing the object image at each incident and viewing angles. Spatial and spectral distribution of ambient light sources in the scene was obtained using an RGB digital camera and a fisheye lens. The spectral distributions of object surface reflectance and the intensity of light sources are estimated from the RGB camera sensor outputs without camera sensitivity functions. The spectral distribution of objects and light sources in the scene is statistically analyzed by measuring the Macbeth color chart with the RGB camera and spectral radio photometer. In the rendering part, a reflection model describing reflectance properties of object surface is developed and the reflection model is implemented to Graphics Processing Unit (GPU) for improving rendering performance. Finally, we render a realistic image of the art object and confirm the validity of the proposed method visually.

Key words: Computer Graphics, Multi-spectral based rendering, Image Reproduction, Art Objects, Reflection Model, Digital Archive.

1. Introduction

Computer graphics technology is recently used for 3 dimensional (3D) image reproduction of art objects in digital archive. A previous work on digital archive has originally reproduced based on making color-calibrated images from the original object [1]. However, the method is not sufficient for rendering realistic images of including gloss and specular highlight. To render precisely the art object, it is needed to develop a reflection model for describing reflection property for surface substances of the art object. The present study proposed a method for estimating various parameters of the reflection model using the image data of object surface. In natural scenes, many illumination sources are present. Illuminant estimation in natural scenes includes the problem of estimating a spatial distribution of light sources by omni-directional observation. Previous works on image rendering for digital archive were limited to RGB color images. The RGB color image is device-dependent and valid for only the fixed conditions of illumination and viewing. Multi-spectral information is more important and useful than color information for image rendering of art objects.

The present study described a method for rendering art objects based on multi-spectral reflection model and multi-spectral ambient light source information in natural scene. We suggest methods for (1) development of multi-spectral reflection model, (2) measurement of the art object, (3) measurement of spatial and spectral distribution of ambient light sources, and (4) implementation of proposed method to Graphics Processing Unit (GPU) for improving rendering performance.

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Unit (GPU) for improving rendering performance. The overall feasibility of our method is confirmed based on computer graphics images created by our rendering system.

2. Multi-spectral reflection model

We describe a multi-spectral reflection model based on the Torrance-Sparrow model[2]. Figure 1 shows reflection geometry of the Torrance-Sparrow model. In this model, an object surface is assumed to consist of planar microscopic facets. The vector \( \mathbf{H} \) is the normal vector of a microscopic facet (micro view). \( \mathbf{N} \) is the normal vector of the object surface (macro view). The vector \( \mathbf{L} \) is the incident light vector, and \( \mathbf{V} \) is the viewing vector. \( \theta_i \) is the incident angle, \( \theta_v \) is the viewing angle, \( \phi \) is the angle between \( \mathbf{N} \) and \( \mathbf{H} \), and \( \theta_i \) is the incident angle to micro-facet. Figure 2 shows diagram of light reflection of the proposed model. The color-signal \( C(\lambda) \) of visual system from a reflective object surface is described as

\[
C(\lambda) = a \cos \theta_i S(\lambda) E(\lambda) + \beta \frac{F(n(\lambda), k(\lambda), \theta_0) D(\phi, \mu) G(N, V, L)}{\cos \theta_i} E(\lambda) ,
\]

where scalar values \( a \) and \( \beta \) are, respectively, intensities of the diffuse and specular components. \( S(\lambda) \) is the spectral reflectance. \( E(\lambda) \) is the spectral distribution of illumination. \( \lambda \) is the wavelength. Function \( D \) is described as surface roughness function. \( \mu \) provides an index of surface roughness. Function \( G \) is a geometrical attenuation factor. Function \( F \) represents the Fresnel spectral reflectance. These parameters are the index of refraction \( n(\lambda) \) and the absorption coefficient \( k(\lambda) \).

3. Measuring of object surface reflection properties

3.1 Measurement system

The reflection model parameters are estimated as the object surface reflection properties[3]. Figure 3 shows the scene for measuring reflection properties of the object surface. The apparatus consists of a light source, two goniometric rotating arms, and an RGB digital camera system. The system can be controlled electrically by PC. Figure 4 depicts the schematic diagram of the measuring system. Object sample is stetted on the object table with rotation arms.

3.2 Estimation of reflection model parameters

The reflection intensity depends on the reflection model parameters, such as constant coefficient \( \alpha, \beta, \mu \). Therefore the problem of estimating the reflection model parameters can be solved as the fitting problem of refractive intensity on the object surface at each incidence and viewing geometry. That is, the model function with unknown \( \alpha, \beta, \mu \) are fitted to the intensity data of reflection acquired at different angles of \( \theta_i \) and \( \theta_v \).

3.3 Estimation of spectral distribution function

The color signal is estimated from RGB camera sensor outputs. The camera sensor output is described by the color signal \( C(\lambda) \). The sensor output vector \( \mathbf{\rho} = [R, G, B]^T \) is described as

\[
\mathbf{\rho} = \int_{400}^{700} C(\lambda) \begin{bmatrix} R_x(\lambda) \\ R_y(\lambda) \\ R_z(\lambda) \end{bmatrix} d\lambda ,
\]

where \( R_x(\lambda), R_y(\lambda), R_z(\lambda) \) are, respectively, the spectral sensitivity functions of sensor RGB.

In order to estimate the continuous function of spectral information in visible light range [400-700nm], we statistically analyzed the spectral distribution of objects and light sources in the scene by measuring of the
Macbeth color chart with the RGB camera and spectral radio photometer at the same scene. We have developed the estimation algorithm based on the Schmitt method\[4\], supposing that spectral reflectance is expressed in an n-dimensional vector. Let $\mathbf{s}$ be an $n \times 1$ matrix of spectral distribution, and the basis function vector $\mathbf{b}_1, \mathbf{b}_2, \mathbf{b}_3$ are determined by finding three principal components of the spectral distribution of the color chart. In this model, an estimate matrix $\mathbf{s}$ of spectral distribution can be determined by

$$\mathbf{s} = w_1 \mathbf{b}_1 + w_2 \mathbf{b}_2 + w_3 \mathbf{b}_3.$$ 

The scalars $w_1, w_2, w_3$ are weight coefficients of basis functions. This model is effective in the sense that the number of unknown parameters can be reduced significantly when spectral distribution functions with continuous spectra are represented by only a small number of basis functions. That is, we have only to estimate weight values $w_1, w_2, w_3$ as spectral distribution function. Let $\mathbf{P}$ is $m \times 3$ matrix of a set of camera sensor outputs, where $m$ is number of pixel. Let $\mathbf{W}$ is $3 \times m$ matrix of a set of weight of basis functions. Weight matrix can be calculated as $\mathbf{W}^T = \mathbf{P} \mathbf{M}$, where $\mathbf{M}$ is the system transformation matrix of RGB-Weight values. $\mathbf{M}$ can be described as $\mathbf{M} \mathbf{P}^+ \mathbf{W}^T$, where $\mathbf{P}^+$ is generalized by inverse of $\mathbf{P}$.

4. Measuring of spatial and spectral distribution in natural scene

We obtain spatial and spectral distribution of ambient light sources in the scene by using RGB digital camera. Spectral distributions of light sources are estimated from RGB camera outputs without camera sensitivity functions. We use an RGB digital camera (Canon EOS 5D) and a fisheye lens(SIGMA Fisheye 8.5mm). We need a very high dynamic range for the camera to observe a wide range of light source from dark shadow to direct sunlight. The camera which has 12-bit dynamic range is used to improve the resolution of intensity quantization. Moreover, to extend the dynamic range of the camera, pictures of the same scene are taken using different shutter speeds. The multiple images are combined into a single image. In order to represent the spatial distribution of ambient lighting, we create an omni-directional image(ambient light map) in a polar coordinate system. A set of the light vectors $\mathbf{L}$ points in all directions from the camera location. We can produce an omni-directional image observed at the center point. Let $(x_s, y_s, z_s)$ be the vector elements of the $\mathbf{L}$. The light vector is expressed in the polar coordinates $(\theta, \phi)$ by transformation

$$\theta = \tan^{-1}\left(\frac{y_s}{\sqrt{x_s^2 + z_s^2}}\right), \quad \phi = \tan^{-1}\left(\frac{x_s}{z_s}\right).$$

Calculation of the spectral distribution $E(\lambda)$ of Eq.(1) looking in all directions of $(\theta, \phi)$ provides the omni-directional image.

5. Image rendering

Once we know all the rendering parameters, we can create precisely the computer graphics images under ambient light. The proposed method is implemented to Graphics Processing Unit(GPU), supposing a color monitor as the display device for the rendering results. The tristimulus values CIE-XYZ of the spectral radiance are calculated as

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \int \mathbf{C}(\lambda) \begin{bmatrix} \overline{E}(\lambda) \\ \overline{D}(\lambda) \\ \overline{A}(\lambda) \end{bmatrix} d\lambda,$$

(4)

Finally Figure 5 shows a computer graphics image created with the estimated parameters under ambient light.
6. Conclusions
We have proposed method for rendering the art object based on multi-spectral reflection model and multi-spectral ambient light source information in the natural scene. In this paper, the reflection properties of the object surfaces and distribution of light sources in the natural scene are realized from camera data. It was possible to render images of the art object under ambient light in the natural scene. An experiment using an art object has demonstrated the feasibility of the proposed method.

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References