Estimation of Reflection Properties of Paintings and its Application to Image Rendering

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Abstract

A method is described for estimating the 3D reflection properties of painting materials such as oil paints and water paints. A gonio-spectral photometer is used for measuring light scattered from a variety of painting surfaces. The reflectance data are acquired at different incident and viewing geometries. The Torrance-Sparrow model is used for describing light reflection on the painting surfaces. An algorithm is presented for determining the model parameters, including spectral reflectance, specular intensity, surface roughness, and refraction index, from the observed spectral reflectance data. Some difference in reflection properties is suggested between oil paints and water paints. Images of the two painting objects are rendered in an experiment.

Introduction

The authors developed a technique for estimating several surface properties of art paintings from camera data and rendering the realistic color images under various illuminations and viewing conditions [1]-[2]. The surface reflection properties of an object include such optical quantities as surface-spectral reflectance, specular intensity, surface roughness, index of refraction and index of absorption. These are mathematical parameters needed for describing light reflection of an object surface. In the previous works, we used a common mathematical model with the same parameters for representing art paintings. It should be noted that the reflection properties depend greatly on its surface material. Therefore it is meaningful to investigate the reflection properties on different materials used for art paintings.

The present paper describes a method for estimating the 3D reflection properties of painting materials such as oil paints and water paints. We use a gonio-spectral photometer for precisely measuring light reflected from a variety of painting surfaces. The Torrance-Sparrow model [3] is used for modeling three-dimensional (3D) light reflection. An algorithm is presented for determining various model parameters from the observed spectral reflectance data. We suggest that there are some difference in reflection properties between oil paints and water paints. Finally we demonstrate some image rendering results.

3D Light Reflection Model

Certain gloss or highlight appears on a painting surface. The surface material is regarded as an inhomogeneous dielectric material like plastics. Light reflection for this material is composed of two reflection components, diffuse (body) reflection component and specular (interface) reflection component, that is described as is described as the dichromatic reflection model.

When using the Torrance-Sparrow model, the spectral radiance of light reflected from a surface is represented as

$$Y(\lambda) = \alpha \cos\theta_i S(\lambda) E(\lambda) + \beta \frac{D(\varphi,\gamma) F(\theta_Q, n) G(\mathbf{N},\mathbf{V},\mathbf{L})}{\cos\theta_r} E(\lambda) \,, \tag{1}$$

where the first term represents the diffuse reflection and the second term represents the specular reflection, respectively. α and β are the weighting coefficients. **N, V,** and **L** are the vectors of surface normal, viewing, and incident light. θ_i, θ_r and φ are the angles of incidence, viewing, and the angle between **N** and normal vector of micro facet. $S(\lambda)$ is the spectral reflectance function and $E(\lambda)$ is the spectral distribution of illumination. The term D is the distribution function representing the micro facet orientation and shows the index of surface roughness. The term F is Fresnel reflection. The term G is attenuation factor. This term is considered the interference rate of micro facets.

Estimation of reflection properties of paintings

The observed spectral reflectance data from a gonio-photometer are used for determining the above reflection model. The spectral reflectance $S(\lambda)$ is determined directly from the spectro-photometer, and the illuminant $E(\lambda)$ is measured separately. Therefore, the unknown parameters in the reflection model are the refractive index n, the intensity of the specular component β and the surface roughness γ.

We made two sets of painting samples for oil and water. Each set consists of 19 samples. For making these samples, we painted different color materials on black acrylic plates with a spatula. Figure 1 shows the painting samples for oil and water. Figure 2 shows the measured spectral radiance factors at the incident angle of 30 degree as a function of viewing angle. The specular reflection occurs around the viewing angle of 30 degree. We measured the spectral reflectance for each sample in the range of light incidence from 10 to 60 degrees at 10 degrees interval. For each incident angle, the viewing angle was changed from -80 to 80 degrees. In order to increase the measurement accuracy, we sampled the viewing angle at 0.5 degree interval within the range from -10 to 10 degrees on highlight peak.

The reflection model function was fitted to the observed spectral radiances by the method of least squares, which minimizes the squared error between the observed radiance factor and the estimate. In this fitting computation, we used the average radiance factor over the entire incident angles and viewing angles. Figure 3 shows the fitting results of the model function to the measured radiance factors. There are some discrepancies between the model and the measurements at the lower sides of the highlight peaks. Note that we have a good fitting result at highlight peak regions.

Figure 4 shows the histograms of the two parameters estimated for surface roughness (left) and refractive index (right). The left figure suggests that oil paints are generally rougher than water paints. The right figure suggests that the refractive index for oil paints is larger than the one for water paints. Moreover we measured the refractive indices of oil and water paints directly by using the Abbe refractometer. The estimated indices are almost coincident with the direct measurement results. Thus we note that the surface appearances of water paint and oil paint are different, depending on the surface roughness and the refractive index.

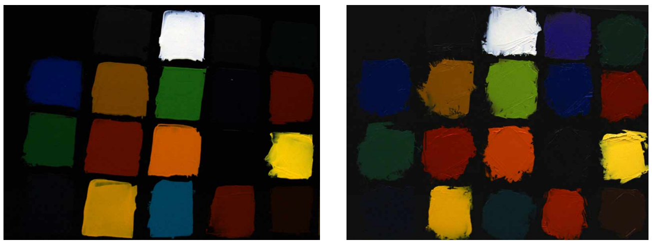

Figure 1 *Color samples of water paint and oil paint*

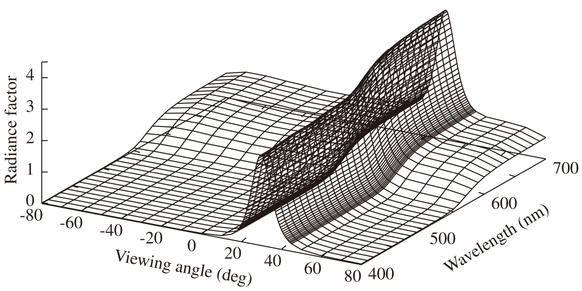

Figure 2 *Measured spectral radiance factors as a function of viewing angles.*

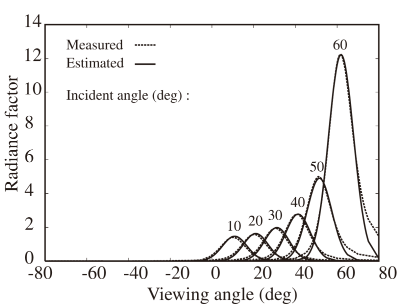

Figure 3 *Fitting results of the model function to the measured radiance factors.*

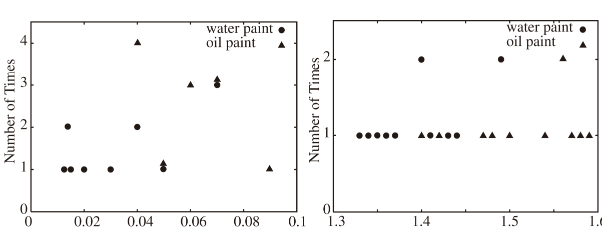

Figure 4 *Histograms of surface roughness (left) and refractive index (right).*

Rendering application

We render color images of the two types of objects for both water and oil paints by using the estimated reflection parameters. The ray-tracing algorithm based on wavelength computation was used for realistic 3D images under arbitrary conditions of illumination and viewing. Figure 5 demonstrates the computer graphics images of a cylinder with blue paints. The left image is for water paint and the right is for oil paint. The same spectral reflection value of $S(\lambda)$ is used for both objects. We assume that the illuminant is D65 with parallel beam. The surface roughness is 0.04 for water and 0.07 for oil. The refractive index is 1.40 for water and 1.52 for oil. Comparison between two pictures in Figure 5 shows clearly difference in appearance between oil paint and water paint that is caused by the estimated reflection parameters.

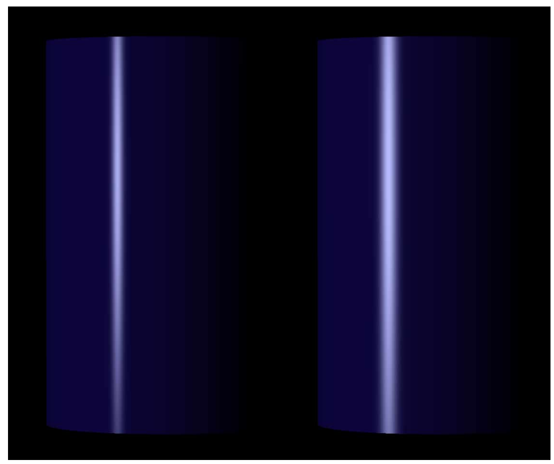

Figure 5 *Computer graphic images of water paint (left) and oil paint (right) with the estimated parameter*

Conclusion

We have estimated the surface reflection property for oil paints and water paints. First, we have used a gonio-spectral photometer for precisely measuring light reflected from a variety of painting surfaces. The Torrance-Sparrow model has been used for describing the 3D reflection properties of painting materials. Next, an algorithm has been presented for determining various model parameters from the observed spectral reflectance data. Finally, we have rendered color images of the two types of objects for both water and oil paints by using the estimated reflection parameters.

References

[1] S. Tominaga and N. Tanaka, 3D Recording and Rendering of Art Paintings, Proc. Ninth Color Imaging Conf., pp. 337-341. (2001).

[2] S. Tominaga and N. Tanaka, Measuring and Rendering Art Paintings Using a RGB Camera, Proc. of EUROGRAPHICS, pp. 299-306. (2002).

[3] K. E. Torrance and E. M. Sparrow, "Theory for off-specular reflection from roughened surfaces", J. Opt. Soc. Am A, 57, pp. 1105-1114. (1967)