BRDF Measurement and Color Appearance Simulation based on iccMAX Framework

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ABSTRACT

A method for evaluating BRDF parameters of Blinn-Phong model via a hemisphere instrument is proposed. A VR simulator are created to simulate the material appearance. iccMAX framework were implemented and evaluated with different lighting geometries. The results show that appearance of different types of objects can be simulated accurately based on the BRDF measurement via iccMAX framework.

KEYWORDS: appearance simulation, color management, BRDF measurement

INTRODUCTION

Digital archives aim to present and protect cultural relics for their truest and most beautiful side in a digitized way [1]. ICC profiles have been widely used in digital archives to preserve the color information of the relics. However, their surface properties such as glossiness and texture have not yet been recorded using the conventional ICC system. For a glossy surface, the visual appearance significantly affected by the viewing and lighting geometries. Specular highlights would appear, and colors would change for a metal surface. As cultural relics include variety of 3D shapes and materials, recording total appearance of the relics become more important for their on-line virtual exhibition [2]. ICC is currently working on iccMAX [3]. The new ICC system is able to perform complex device characterization, spectral imaging, BRDF (Bidirectional Reflection Function) measurement, material identification and visualization as it supports arbitrary and programmable transforms. It is the time to study how to accurately reproduce surface property with the iccMAX.

BRDF MEASUREMENT

Four types of Pantone samples, Metallics, Coated, Uncoated, Cotton, were measured by a Radiant Zemax IS-SA™ system. The IS-SA™ is capable of measuring a full hemisphere of scattered light at once, dramatically reducing the time required to obtain a BRDF measurement. Referring to Figure 1, the 2D sensor gains the hemisphere XYZ values, which are used to estimate parameters of surface appearance rendering models, such as Blinn-Phong, Cook-Torrance and Ward models, to create BRDx profiles in iccMAX format.

The BRDF (denoted as f_r) determines how reflected radiance is distributed in terms of the distribution of incident radiance:

$$f_r(\theta_i,\phi_i;\theta_r,\phi_r)=\frac{dL_r(\theta_i,\phi_i;\theta_r,\phi_r;E_i)}{dE_i(\theta_i,\phi_i)} \tag{1}$$

Where the subscript r is the reflection while i is associated to incident quantities; L_r denotes the reflected radiance; and E_i denotes the incident irradiance. The geometry and the measurement setting of the BRDF are described in Figure 1.

As can be seen in the *Figure 1*, a light source illuminates a surface element *dA* through the element of solid angle $d\omega_i$ from the incident direction expressed in polar coordinates (Θ_i, $\varnothing_i$). The reflected flux is in the direction (Θ_r, $\varnothing_r$) centered within the solid angle $d\omega_r$. In this study, we set the lighting angle Θ_i as 10° to 80° in 10° interval, the azimuth angle $\varnothing_i$ is at 90°, the viewing angle Θ_r as 0° to 85° in 1° interval, the azimuth angle $\varnothing_r$ is at 0° to 359° in 1° interval.

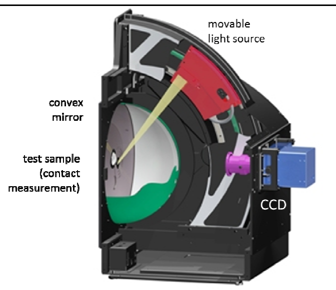
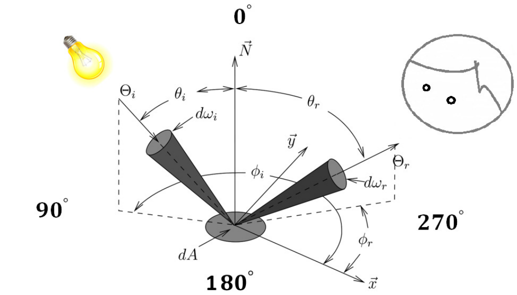
Structure	Measuring geometry
	

Figure 1. The structure and measuring geometry of the IS-SA™ system.

BRDF PARAMETERS

The multi-angular XYZ data can be used to derive appearance parameters for popular 3D shaders such as Blinn-Phong model.

iccMAX provides several new features which can be used to transform device values to BRDF parameters that can be used to simulate color appearance under various viewing/illumination geometries. The brdfTransformStructure type element defines the type of BRDF transform. If the type sub-tag contains the signature 'mono' then the brdfTransform sub-tag shall be assumed to define output BRDF parameters using only a single channel of data. The total number of parameters shall be defined by the value stored in the paramsPerChannel sub-tag element. If the type sub-tag contains the signature 'colr' then the brdfTransform sub-tag shall be assumed to define output BRDF parameters for each channel defined by the associated PCS elements in the header. The total number of parameters for each output entry shall be defined as the number of PCS channels multiplied by the value stored in the paramsPerChannel sub-tag element. We use the Blinn-Phong reflection model as an example. The lighting equation used by the Blinn-Phong reflection model is as follows:

$$I_p = \sum_{m\in lights}\left(k_d\left(\hat{L}_m \bullet \hat{N}\right)i_{m,d} + k_s\left(\hat{N} \bullet \hat{H}_m\right)^n i_{m,s}\right) \tag{2}$$

Where $i_{m,d}$ is the intensity of the diffuse component of light m. $i_{m,s}$ is the intensity of the specular component of light m. $\hat{L}_m$ is the direction vector from the light to the location on the surface. $\hat{N}$ is the normal for the location on the surface. $\hat{H}_m$ is the direction vector midway between *L* and the viewpoint vector *V*. I_p is the total light reflected from the surface of the object towards the viewer. K_d, K_s, and *n* are the Blinn-Phong parameters that specify the material. K_d is the diffuse reflection constant for the material. K_s is the specular reflection constant for the material. *n* is the shininess constant for the material. For the full color Blinn-Phong function the three parameters shall be K_d, K_s, and *n*. The monochrome function combines the output of the absolute transform with three parameters to compute the Blinn-Phong parameters K_d and K_s.

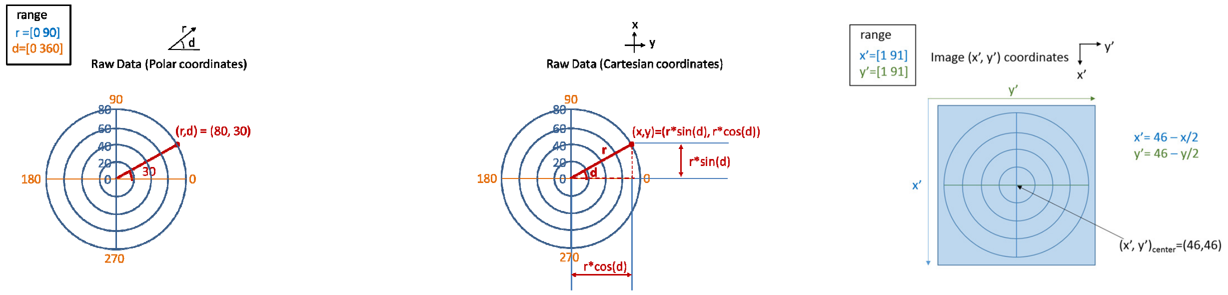
$$k_d = I_d B \tag{3}$$

$$k_s = I_s B + I_{gs} \tag{4}$$

Where B is the output of the absolute transform, I_d is the diffuse scaling factor, I_s is the specular scaling factor, and I_{gs} is a global specular component. The order of the four parameters in the transform shall be: I_d, I_s, I_{gs}, and n.

3.1 BRDF parameter fitting

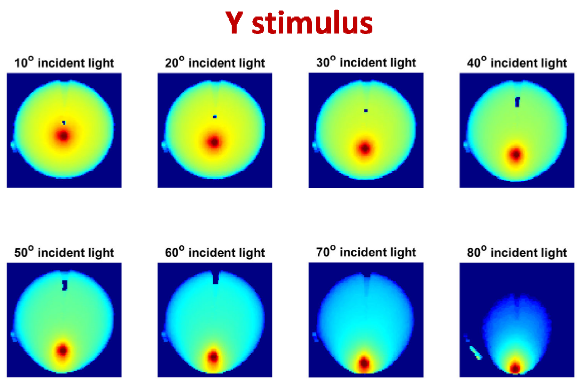
The BRDF parameters of the Blinn-Phong model can be obtained by fitting the measured BRDF data. We convert IS-SA raw data to images shown as Figure 3(a). The coordinate transform is from polar coordinates (see Figure (a)) to Cartesian coordinates(see Figure (b)) which is also the image coordinates(see Figure (c)).



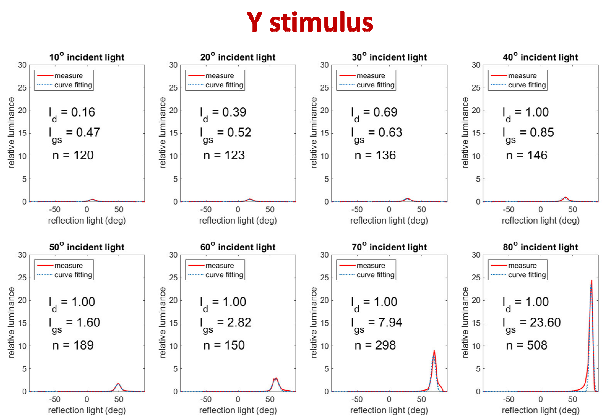
(a) Polar coordinates *(b) Cartesian coordinates* *(c) Image coordinates*

Figure 2: BRDF data coordinate transform

We use the measurement of a red coated paper as an example. The XYZ images are similar and the Y image is shown in Figure 3(a). The blue holes in the upper-half area are the camera position. The area cannot provide accurate reading. The reading can be replaced by interpolated values of surrounding areas.



(a) Normalized Y stimuli with pseudo-colors.



(b)

Figure 3: (a) BRDF Y image and (b) the curve fitting in vertical directions.

We applied a least-squared curve fitting for Blinn-Phong reflection model which fit it to 50 degree incident light (Figure (b)). We found that monochrome BRDF parameters across X, Y and Z channels are very similar. I_s are normally very small so as to ignore them. We also found that limit upper boundary of I_d to 1 could improve the accuracy of curve fitting.

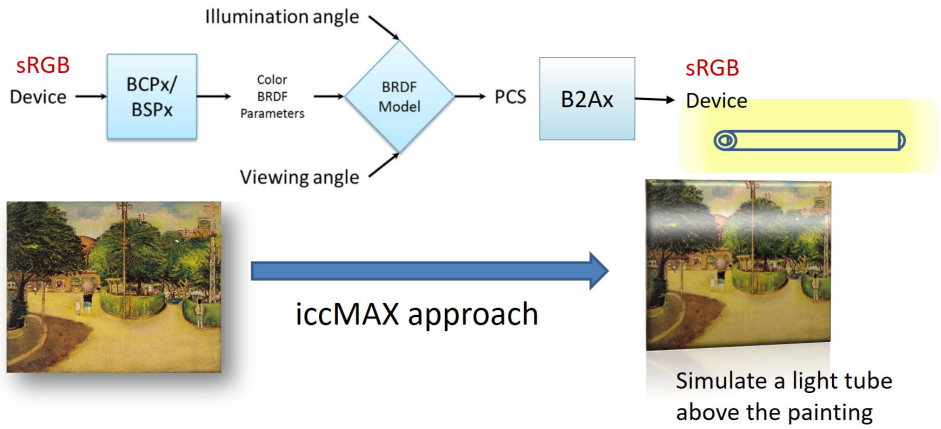


Figure 4: Appearance simulation using the iccMAX framework

APPEARANCE SIMULATION

The BRDF parameters can be used to simulate color appearance of a material based on the the iccMAX framework. A VR simulator we made in Matlab platform are used to simulate the material appearance with adjustable lighting geometry. Figure 4 shows an example of glossy paint simulation. The iccMAX framework were implemented by (1) regard sRGB as the device space, (2) convert an input sRGB photo from sRGB space to XYZ space with brdfColorimetricParameter (BCP1) which contains (I_d, I_s, I_{gs}, and n) for each of XYZ channel, (3) apply Color BRDF Parameters (k_d, k_s, n) to each pixel, (4) input illumination angle and viewing angle to predict XYZ values of each pixel via the Blinn-Phong model, (5) compress highlight using a knee function, the tone compression is needed to avoid highlight clipping. (6) convert the scaled XYZ values to sRGB space via a B2A1 sRGB profile. The results of appearance simulation are reasonable which match the visual appearance of the test samples very well.

CONCLUSION

We have done BRDF measurement of many read-world samples using the IS-SA™ system. We also proposed a method for evaluating BRDF parameters of Blinn-Phong model from the measurement. Our results show that appearance of different types of objects can be simulated accurately based on the BRDF measurement via the iccMAX framework.

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