Calibration of remote sensing image using BRDF model

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A new bidirectional reflectance distribution function (BRDF) model of earth objects is established for the calibration of remote sensing image by the national metrology equipment. This model colligates the solar radiance, the atmosphere status, the object type, and the space camera parameter, etc. The output data of this model is the enter radiance data for the space camera. The remote sensing image can be appeared more "true" through this calibration. A kind of ground glass for architecture is measured and the correspond remote sensing image is simulated. After calibrated, the chromatism of this image is improved by 2 and the luminance contrast of that is improved by 3.

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The aero camera receives different radiance and emit different wavelength light at the same time for the generation of the remote sensing image. Bidirectional reflectance distribution function (BRDF) combine these incident light, reflect light, and scatter light in one variable and it is the best variable to describe the space radiance performance of objects. The complex BRDF model for remote sensing image is based on the BRDF fundament equation, and colligates the solar radiance, the atmosphere status, the object type, and the space camera parameter, etc. In this model, the solar radiance and it's change through atmosphere are considered in the incident variable of BRDF, and the proximity effect of atmosphere and the parameters of aero camera are considered for the reflect variable of BRDF, for example, the BRDF performance of aerosol[1]. Then the BRDF value of some typical objects are measured and calibrated. The absolute BRDF value are achieved and simulated using the complex BRDF model. Thus the remote sensing image which is calibrated is achieved. The whole procedure is shown in Fig. 1.

The basement equation of the complex BRDF model is established by the definition of BRDF as shown in Eq. (1) which defined as the ration of the reflect radiance and the incident irradiance on the appearance of the objects[2]. In Eq. (1), θ_i represents the incident zenith angle, φ_i represents the incident azimuth angle, θ_r represents the incident zenith angle, φ_r represents the incident azimuth angle, λ the represents wavelength, $L_\mathrm{r}(\theta_\mathrm{i},\varphi_\mathrm{i},\theta_\mathrm{r},\varphi_\mathrm{r},\lambda)$ represents the reflect radiance at specified angles and wavelength, $E_\mathrm{i}(\theta_\mathrm{i},\varphi_\mathrm{i},\lambda)$ represents the incident irradiance at specified angles and wavelength. Equation (1) is true in the controllable incident solid angle $d\varOmega_\mathrm{i}$, which is shown in Fig. 2. Under this condition, $L_\mathrm{r}(\theta_\mathrm{i},\varphi_\mathrm{i},\theta_\mathrm{r},\varphi_\mathrm{r},\lambda)$ can be simplified to $L_\mathrm{r}(\theta_\mathrm{r},\varphi_\mathrm{r},\lambda)$.

$$f_\mathrm{r}(\theta_\mathrm{i},\varphi_\mathrm{i},\theta_\mathrm{r},\varphi_\mathrm{r},\lambda)=\frac{\mathrm{d}L_\mathrm{r}(\theta_\mathrm{i},\varphi_\mathrm{i},\theta_\mathrm{r},\varphi_\mathrm{r},\lambda)}{\mathrm{d}E_\mathrm{i}(\theta_\mathrm{i},\varphi_\mathrm{i},\lambda)}=\frac{L_\mathrm{r}(\theta_\mathrm{r},\varphi_\mathrm{r},\lambda)}{E_\mathrm{i}(\theta_\mathrm{i},\varphi_\mathrm{i},\lambda)}. \tag{1}$$

The calibration equation of this BRDF model is established by using the national metrology equipment. A operator K_f which named BRDF absolute calibration operator is defined based on Eq. (1) as[3]

$$K_\mathrm{f}=\frac{1}{L_\mathrm{r}(0,0,180,0,\lambda)\varOmega_\mathrm{r}}. \tag{2}$$

K_f is achieved by measuring the incident radiance at the vertical angle and the corresponding solid angle. Then the BRDF absolute calibration model can be represented as

$$f(\theta_\mathrm{i},\varphi_\mathrm{i},\theta_\mathrm{r},\varphi_\mathrm{r},\lambda)=K_f\frac{L_\mathrm{r}(\theta_\mathrm{i},\varphi_\mathrm{i},\theta_\mathrm{r},\varphi_\mathrm{r},\lambda)}{\cos\theta_\mathrm{i}}. \tag{3}$$

The incident solar radiance is changed when it passes the atmosphere. So the incident radiance of the earth objects includes the direct solar light and the scatter solar light. All these lights can be reflect by the earth objects[4]. The direct solar light at specified angles can be calculated according to the distance between the earth and the sun -r and the solar constant at the corresponding angles $E_0(\theta_\mathrm{i},\varphi_\mathrm{i},\lambda)$ as shown in

$$E_\mathrm{r}(\theta_\mathrm{i},\varphi_\mathrm{i},\lambda)=(r/r_0)^2E_0(\theta_\mathrm{i},\varphi_\mathrm{i},\lambda). \tag{4}$$

This solar light irradiate at zenith angle θ_i, the corresponding transmit ratio of the atmosphere is $\tau_\mathrm{i}(\lambda)$, then

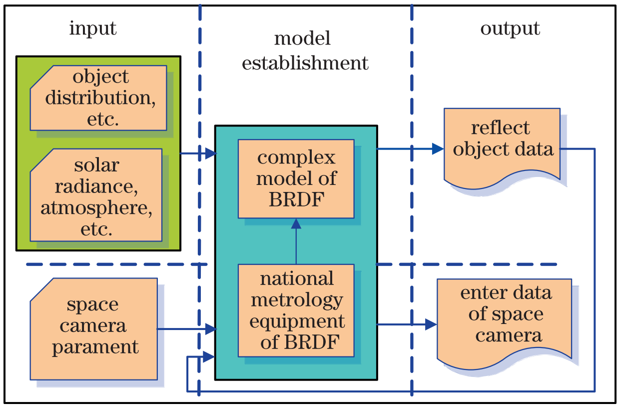

Fig. 1. Establish procedure of the complex BRDF model for the remote sensing image.

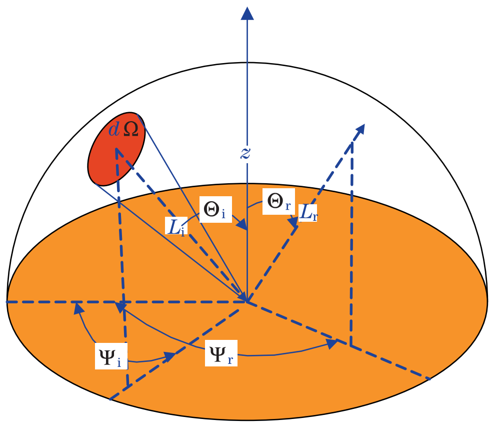

Fig. 2. Schematic of BRDF.

the solar radiance which reaches the earth object at specified angles $E_s(\theta_i, \varphi_i, \lambda)$ can be represented as

$$E_s(\theta_i, \varphi_i, \lambda) = E_r(\theta_i, \varphi_i, \lambda)\tau_i(\lambda)\cos\theta_i. \tag{5}$$

The scatter solar light may be scatted and reflected by the atmosphere many times. These scatter solar lights considered only once because other lights are little and the influence is also limited. Then the scatter incident radiance $E_d(\theta_i, \varphi_i, \lambda)$ is represented as

$$E_d(\theta_i, \varphi_i, \lambda) = \int_{\varphi=0}^{2\pi}\int_{\delta=0}^{\pi/2} L_d(\theta_i, \varphi_i, \lambda)\cos\theta_i \sin\theta_i \mathrm{d}\theta_i \mathrm{d}\varphi_i, \tag{6}$$

where $L_d(\theta_i, \varphi_i, \lambda)$ represents the radiance on the earth object from the scatter solar light.

Thus the BRDF absolute model through reflection by the earth object is established as

$$L_r(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) = [E_s(\theta_i, \varphi_i, \lambda) + E_d(\theta_i, \varphi_i, \lambda)] \cdot f(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda). \tag{7}$$

The absorption of the atmospheric molecules and aerosol will influence the radiance procedure because of the existing of atmosphere and aerosol[5]. So the proximity effect of the atmosphere should be considered. All these influence can be integrated as one weight function which as shown in Eq. (8) for earth object unit (x, y):

$$F(x, y, \lambda) = \int_0^H \frac{\beta(\lambda)\rho(x, y, z)\cos\theta_i\tau_i(\lambda)\tau_r(\lambda)}{4\pi(x^2+y^2+z^2)\tau(\lambda)}\mathrm{d}z, \tag{8}$$

where $\beta(\lambda)$ represents the sum of the scatter coefficients of the atmospheric molecules and the aerosol; $\rho(x, y, z)$ represents the scatter phase function; z represents the height; $\tau_i(\lambda)$ represents the corresponding transmit ratio of the atmosphere.

$$F(x, y, \lambda) = \frac{1}{\mathrm{d}x\mathrm{d}y}, \text{ when } x = y = 0. \tag{9}$$

Thus the BRDF absolute model for earth object unit (x, y) including the proximity effect can be represented as

$$L(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) = E_c(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) f(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) \cdot \iint F(x, y, \lambda)\mathrm{d}x\mathrm{d}y, \tag{10}$$

where

$$E_c(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) = E_s(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) + E_d(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda).$$

Equation (10) is the final model of the complex BRDF model for earth observe. It is the key step of the calibration procedure as shown in Fig. 1.

The BRDF of a kind of ground glass for architecture is measured using the national metrology equipment in China. Some typical measurement angles are selected as φ_i=0°, φ_r=180°, θ_i is changed between 20° and 85°, θ_r is changed between 85° and –85°. The measurement results of the absolute BRDF value are shown in Fig. 3 (wavelength=512 nm). Form these data curves, this ground glass can be considered as a better diffuse material which approaches to lambert model.

Furthermore, the BRDF in different reflect azimuth angles φ_r are measured when φ_i=0° and φ_i=60°, φ_r=60° and φ_i=85°, φ_r=85°. The results of these absolute BRDF measurement are shown in Fig. 4 (wavelength=512 nm).

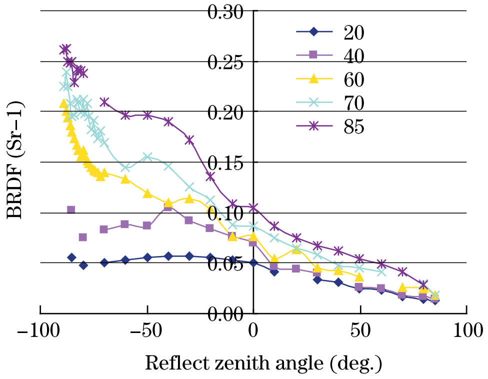

Fig. 3. Absolute BRDF curve 1 of a kind of ground glass for architecture.

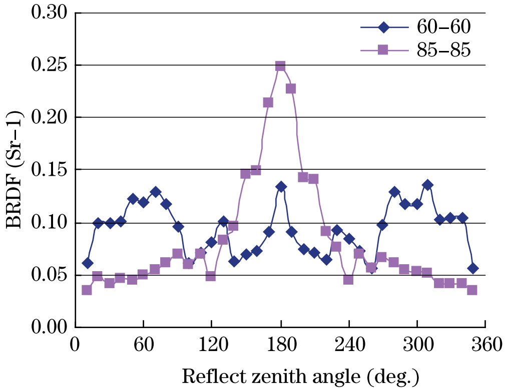

Fig. 4. Absolute BRDF curve 2 of a kind of ground glass for architecture.

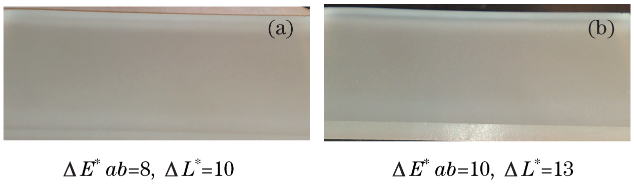

Fig. 5. Images of the ground glass architecture (a) before calibration and (b) after calibration.

The performance of this ground glass for architecture when the zenith angle and azimuth angle change separately are achieved through these two kind of measurements. All these data are the input of the simulated procedure as shown in Fig. 1 and the simulated image with calibration is achieved. Figure 5 shows the image of the ground glass architecture before calibration and the same image which is calibrated by the BRDF absolute model and corresponding measurement data. The maximum chromatism $\Delta E^* ab$ and luminance contrast ΔL^* in every image are given.

In conclusion, the chromatism of this image is improved by 2 and the luminance contrast of that is improved by 3 from the calibration result of the ground glass architecture, Furthermore, this complex BRDF model can be used in the establishment and correct of remote sensing image data, and the simulation of space camera[6,7]. Next work should be concerned on the different correct requirement of BRDF model for different remote sensing objects in order to achieve more "true" remote sensing image.

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