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The degree of polarization modeling with different shapes of the satellite

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ABSTRACT

Polarization is one of the important characteristics of the interaction between light and substance, which relates to the shape and the material of the target. To research the effects of the degree of polarization (DOP) caused by different materials, the polarized bidirectional reflectance distribution function (pBRDF) model has been established by the theory of microfacet. But in this model, the scattering effect of polyhedron is ignored. Based on these researches, the DOP model of satellite with different shapes (cuboid, cylinder and sphere) is set up and simulated. The simulating results show that the DOP of satellite relates with the complex refractive index, shape of satellite, incident angle and view angle. It is also proved that the polarization is a reflection of the characteristics of material, shape of satellite, which provides theoretical support for identifying satellite.

1. Introduction

The major observing method of satellites is optic detection, which contains three ways: photometry, spectrum and polarization. Photometry reflects both the size and motion characteristic of satellites. Spectrum can indicate the feature of the surface material of satellites. Polarization reflects both structure and material characteristic of satellites.

Now, more and more attention is paid to detect satellites with the means of polarization, for example, Stead installed a polarizing analyzer to the photo-electric telescope to observe the polarization of satellites in the Sulphur Grove ground based observing station in the State of Ohio, and the maximum DOP value 39% of a satellite was observed [1]. Kissel's research shows that the polarization of sunlight reflected by the satellite is very high, which is composed of diffuse reflection and specular reflection and he considered that this result proved that polarization could be used to study from the satellite [2]. After observing the polarization of targets of different shapes, Beavers has found that polarization can be a mean of observing the state of targets in orbit, identifying the material of targets, and detecting the influence of optical features of targets exposed in space [3].

Currently, the study on the polarization of satellites is focused on the experimental observation. For example, Thilak modeled the polarized bidirectional reflectance distribution function (pBRDF) model using the theory of microfacet [4]. This model, however, is just a rough surface-based study on scattering properties, without involving the shape and the material of targets. Beavers has measured the DOP curves of the satellite LCS-1 of sphere and COMSTAR D4 of cylinder when the complex refractive index is $\widehat{n} = 3.2 + 5.25i$ and $\widehat{n} = 2.15 + 0i$ respectively [5], as shown in Fig. 1, but the theoretical model is not derived.

In this paper, we propose the DOP model that can reflect the shape and material of satellites, which provide the theoretical basis for satellites detection and identification.

2. Theoretical model

As shown in Fig. 2, the process of polarization model is divided into two aspects. On the one hand, the reflective property is considered as a combination of diffuse reflection and specular reflection, which is on the contrary of the traditional modeling process, which the target surface is regarded as ideal surface of diffuse reflection (Lambertian surface) and the specular reflection is ignored. The specular reflection, however, just reflects the polarization of

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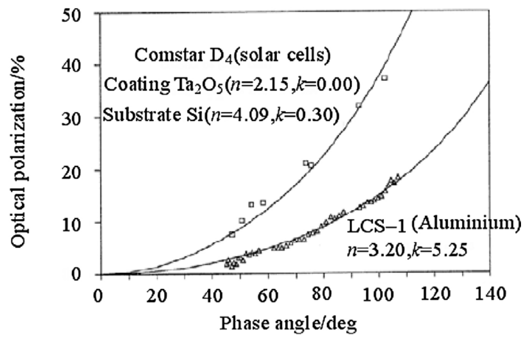

Fig. 1. Polarization phase curves for two types of satellite surfaces.

satellites. Therefore, the traditional Lambertian surface is not taken as the model of satellites. In this paper, according to the surface property of satellites, high order cosine method is used to describe the intensity of sunlight reflected by satellites, and the expression of the total intensity I can be got.

On the other hand, according to the (pBRDF) model using the theory of microfacet, which reflects the material property of satellite, the complex refractive index and the observing phase angle are used to describe the DOP P and polarization angle φ.

According to the definition of DOP P, the DOP of microfacet can be expressed as the ratio of polarizing intensity dE_P and total intensity dE_T where the total intensity is the sum of polarizing intensity and the intensity of diffuse reflection dE_S, which are given

$$P = \frac{dE_P}{dE_T} = \frac{dE_P}{dE_P + dE_S} \tag{1}$$

$$dE_P = \frac{P}{1-P} dE_S \tag{2}$$

We note from Eq. (2) that the polarizing intensity of microfacet is an expression of the intensity of diffuse reflection and the DOP of microfacet. Then the diffuse reflecting model of the different shapes of satellites is modeled, and after calculate integral, the expressions of polarizing intensity E_P can be got:

$$E_P = \frac{P}{1-P} E_S \tag{3}$$

where the different shapes E_S will be analyzed in detail in Section 3.

The polarizing state is usually expressed using Stokes parameter [6], which is defined as:

$$S = [IQUV]^T \tag{4}$$

where I is the total intensity, Q is the result of subtracting vertical line polarizing component from horizontal line polarizing component, U is the result of subtracting the sum of horizontal line polarizing component and vertical line polarizing component from

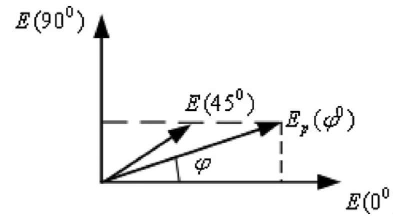

Fig. 3. The decomposing of polarizing intensity vector.

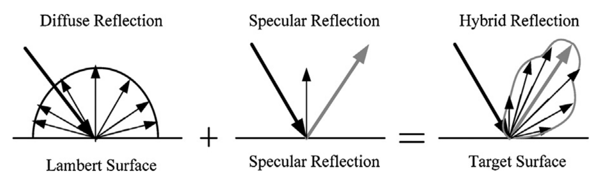

Fig. 4. Analysis of reflection characteristics of space object.

double 45° line component, and because the circular polarizing component of natural targets is a very small value, V is neglected [7].

Fig. 3 illustrates the polarizing intensity E_P and angle φ is decomposed along three polarizing direction: 0°, 45° and 90°. Then three DOP intensities $E(0°)$, $E(45°)$, $E(90°)$ can be got:

$$\begin{cases} E(0^\circ) = \cos\varphi \cdot E_P(\varphi) \\ E(45^\circ) = 1.44 \cdot \sin\varphi \cdot E_P(\varphi) \\ E(90^\circ) = \sin\varphi \cdot E_P(\varphi) \end{cases} \tag{5}$$

and the expressions of Q and U of Stokes parameter is given by Eqs. (6) and (7).

$$Q = E(0^\circ) - E(90^\circ) \tag{6}$$

$$U = 2E(45^\circ) - E(0^\circ) - E(90^\circ) \tag{7}$$

In summary, the DOP expressions of satellites with different shapes can be given by:

$$\mathrm{DOP} = \frac{\sqrt{Q^2 + U^2}}{I} \tag{8}$$

2.1. The scattering model of satellites

The reflecting model of satellites is neither ideal diffuse reflection nor specular reflection, while it is the reflection with both these two, which can be seen in Fig. 4.

According to the surface and reflecting properties of satellites, the high order cosine scattering distribution is used to analyze the optical property:

$$I_\theta = I_0 \cos^n \theta \tag{9}$$

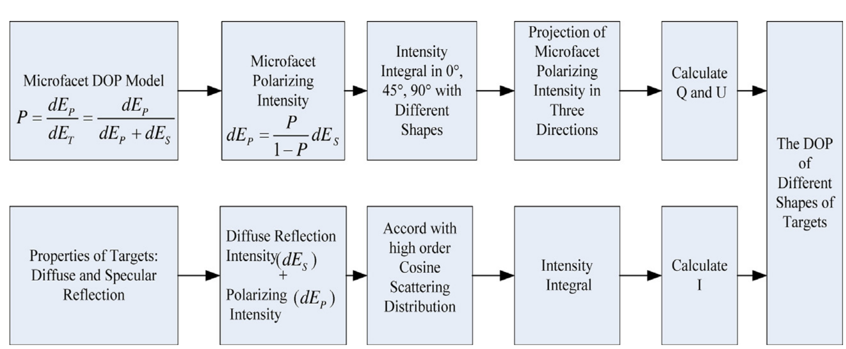

Fig. 2. The flow chart of the modeling process of satellites polarization.