The Study on Equivalent Analysis Method of Optical Scattering Characteristics of Space Objects

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Abstract. The optical observation of Space objects, it is an important component of Space Situation awareness, which is a significant means of obtaining information and developing objects recognition. The optical characteristics are important features of the spatial objectives that allow us to carry out the main elements of optical observation and analysis. In this paper, the target detection, feature extraction and recognition in the space target monitoring task are analyzed and studied systematically, the optical scattering characteristics of the space target and the equivalent analysis of the ground laboratory are analyzed. And the most important influencing factor, atmospheric attenuation, which was analyzed and calculated. Based on MODTRAN, we made the atmospheric attenuation calculation module was developed to correct the atmospheric attenuation factors. Finally, the equivalent analysis of the simulated and actual measurements in the laboratory is carried out and the irradiance of the equivalent space target is obtained.

1. Introduction

Space targets refer to targets that are 150 km away from the surface of the Earth (also known as outer space), including natural objects and man-made orbiters[1][2]. In the field of astronomy, there are many natural objects such as comets, meteors, and stars. In the aerospace field, they are mainly artificial orbiters flying around the Earth and other stars. Based on the optical scattering characteristics of space targets, monitoring, identification and state inversion of targets as an effective method are receiving attention from all countries in the world. At present, the research on the light scattering characteristics of space targets at home and abroad is mainly based on simulation analysis and actual observation. However, with the deepening of research, more and more scholars have found that computer simulation is difficult to establish a mathematical model that accurately restores the optical characteristics of spatial targets, resulting in rougher simulation results. Actual observations have lower efficiency problems, such as sun-synchronous orbits. The target is difficult to observe and other issues. The experimental method can not only make up for the shortcomings such as the low precision of computer simulation, but also solve the problem of low actual observation efficiency. It is a means to analyze the optical scattering characteristics of space objects to analyze the inability of the motion state.
2. Basic principle of equivalent analysis of optical scattering characteristics of space targets

Due to the influence of experimental equipment and experimental conditions, the laboratory will inevitably deviate from the measurement of the light dispersion of real space targets. It mainly shows the attenuation of atmospheric attenuation and transmission distance caused by the difference in distance between the detector and the space target, and the size difference between the space target and the laboratory model.

2.1. Basic design principle of atmospheric attenuation calculation module

First, we selected the three commonly used aerosol models Maritime, Rural, Tropospheric, and Urban in the aerosol models provided by the Modtran model (Figure 1). The specific model parameters are shown in Figure 2.

![Parameter input interface](image1)

Then, we set the humidity parameters separately under the selected aerosol models. The humidity parameters are sampled and collected at intervals of 5 percentage points. Under the same humidity parameters, the parameters such as the observation zenith angle are further set. The zenith angle parameters are sampled and collected at intervals, and the files corresponding to the atmospheric transmittance of different wavelengths under the set conditions are derived from the Modtran software.

![Four classical atmospheric model data selected by the atmospheric attenuation module](image2)

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We are in the process of data sorting, etc. As shown in Figure 3 and Figure 4, it is found that the other three model finishing processes are also consistent with the marine aerosol model. Each
parameter of each aerosol model is equivalent to similar to Figure 4. In the TXT document, the software is based on these TXT documents exported from Modtran for atmospheric attenuation calculation. The specific format of the document is shown in Figure 5. The data format is similar to the original data generated by Modtran. The first column is the wave number, the second column is the total atmospheric transmittance, and the subsequent is the transmittance of different particles.

![Fig. 3 Marine aerosol model data files under different humidity conditions](image)

Finally, we use the Qt platform to program when programming, and add interactive interface to make it complete input and output. By comparing the two attenuation, the atmospheric attenuation factor L in the corresponding environment can be obtained.

![Fig. 4 Data of different zenith angles under zero humidity conditions in marine aerosol models](image)

![Fig. 5 Atmospheric transmittance of marine aerosol model under zero humidity conditions](image)
The working principle is to first give the water vapor transmission rate $H_0$ of the four models under cloudless conditions, and use this as a benchmark, and then give the water vapor transmission rate $H_{C0}$ of the high cloud under 0% humidity under the four models. Also use it as a benchmark.

$$C_0 = \frac{H_0}{H_{C0}}$$

We set the water vapor transmission rate coefficient of cloudless and cloud. $H_0$ is the water vapor transmission rate under cloudless conditions in RU-F, MA-F, UR-F, TR-F, $H_{C0}$ is RU-0%, MA-0%, UR-0%, TR-0%. The water vapor transmission rate in the high cloud 0% humidity condition corresponds to the third column data in the document.

We let $H_{CX1}$ be the water vapor transmission rate under cloudless conditions, and $H_{CX}$ is the water vapor transmission rate under the cloud.

$$H_{CX1} = H_{CX} \times C_0 = H_{CX} \times \frac{H_0}{H_{C0}}$$

The atmospheric transmittance $T_{CX1}$ under different cloud humidity is:

$$T_{CX1} = \frac{T_0}{H_0} \times H_{CX1}$$

$$T_{CX1} = \frac{T_0}{H_0} \times H_{CX} \times C_0$$

$$T_{CX1} = \frac{T_0}{H_0} \times H_{CX} \times \frac{H_0}{H_{C0}}$$

$$T_{CX1} = \frac{T_0 \times H_{CX1}}{H_{C0}}$$

Where $T_0$ is the atmospheric transmittance under cloudless conditions in RU-F, MA-F, UR-F, and TR-F, corresponding to the second column of the document; $H_{C0}$ is RU-0%, MA-0%, UR-0%, TR-0% of the high cloud 0% humidity conditions of the water vapor transmission rate, corresponding to the third column of data in the document; $T_0$, $H_{C0}$ only changes with the angle; $H_{CX}$ for other high cloud conditions The water vapor transmission rate corresponds to the third column of the document. For example, to calculate the atmospheric transmittance of the 12° zenith angle at 5% humidity under the Rural-VIS=23km, then

We take the second column in RU-0-12.txt in RU-F at $T_0$;
We take the third column in RU-0C-12.txt in RU-0% of $H_{C0}$;
We take the third column of RU-5C-12.txt in RU-5% in $H_{CX}$.

Finally, the constraint is imposed: if $T_0=0$, then $T_{CX1}=0$.

2.2. Space target optical scattering characteristics equivalent analysis calculation principle

First of all, in the laboratory, we select a Libertarian whiteboard (Fig. 6) as the calibration board. We can calculate the OCS value of the Lambert whiteboard by formula, and then we can obtain the target model by OCS relative measurement method. OCS value\(^3\). Based on the linear relationship between the spatial target and the laboratory model OCS, the irradiance of the spatial target at the entrance of the detector can be further determined. Finally, considering the attenuation of the optical radiation transmission by factors such as the atmosphere and the distance, it is necessary to further correct the irradiance of the spatial target calculated in the previous step.
The principle of the equivalent analysis of the optical scattering characteristics of the space target is briefly summarized as follows:

1. Calculate the OCS value $OCS_1$ of the laboratory target model.

$$OCS_1 = \rho \times OCS_b$$  \hspace{1cm} (4)

Where, the relative reflectivity of the target model and the calibration whiteboard is the OCS value of the calibration whiteboard.

2. Calculate the OCS value $OCS$ of the spatial target.

$$OCS = C \times OCS_1$$  \hspace{1cm} (5)

Where $C$ is a constant, which is a specific multiple of the OCS of the spatial target and the target model $OCS_b$.

3. Calculate the irradiance of the space target into the enthral.

$$E_1 = \frac{E_{sun} \times OCS}{R^2}$$  \hspace{1cm} (6)

Where is the irradiance of real sunlight at the space target; the value of the real space target; the distance from the real space target to the detector, which can also be equivalent to the distance of the space target from the Earth.

4. Calculate the irradiance of the spatial target through the atmospheric attenuation.

$$E_{target} = \frac{E_1}{L}$$  \hspace{1cm} (7)

Where is the atmospheric attenuation factor obtained by the atmospheric attenuation module. Therefore, the equivalent space target irradiance is

$$E_{target} = \frac{C \times \rho \times E_{sun} \times OCS_b}{L \times R^2}$$  \hspace{1cm} (8)
3. Equivalent Case Analysis of Optical Scattering Characteristics of Space Targets

We chose to use STK to simulate the scene of an observation of an STSS satellite at Lijiang Station, as shown in Figure 7.

![Observation STSS satellite scene by Lijiang station](image)

**Fig. 7** Observation STSS satellite scene by Lijiang station

We set the epoch time of the scene and the number of tracks in the STSS, from 21:18 to 21:30 on July 1st of 2017, a total of 12 minutes, the step size is 30 seconds, the measurement of the model in the laboratory is also 30 seconds is the step size, a set of data is measured every 30 seconds, and a total of 240 sets of data are obtained.

Due to space limitations, we choose the data will be given in the form of a chart, but the actual data used in the processing of the data is the original data, the example analysis and calculation process is as follows:

1. Select the calibration whiteboard, measure the DN value in the laboratory, and convert it into star equivalent and OCS[4]. The experimental environment is shown in Figure 8.

2. According to equation (4), the OCS value of the target model is calculated, as shown in Fig. 9(a).

3. The size ratio of the STSS satellite to the laboratory satellite model is 10:1, and the OCS value of the STSS satellite is obtained as shown in Fig. 9(b).

4. The irradiance of the STSS satellite before atmospheric attenuation is obtained according to equation (6) as shown in Fig. 9(c).

![Lab environment](image)

**Fig. 8** Lab environment

(5) Apply the atmospheric attenuation module to calculate the atmospheric attenuation factor over Lijiang station. Consider the geographical environment of Lijiang, choose the environment type as rural, the humidity is set to 55.3%, and the elevation angle is set to 32.6°. The atmospheric attenuation
factor is obtained by the ratio of the sunlight before and after the attenuation through the atmosphere. As shown in Fig. 10 and Fig. 11, the atmospheric attenuation factor of Lijiang is like this:

\[ L = \frac{809.723}{352.435} = 2.298 \]  

(9)

Fig. 9 Satellite model and OCS of STSS satellite under different conditions

(6) Calculate the irradiance after attenuation through the atmosphere as shown in Fig. 9(d).

Fig. 10 Irradiance outside the atmosphere
4. Conclusion and outlook
In this paper, the target detection, feature extraction and recognition in the space target monitoring task are taken as the application background. The optical scattering characteristics of the space target are analyzed by the combination of laboratory measurement and simulation calculation, and the most important influencing factors are analyzed. The atmospheric attenuation was analyzed and calculated. Based on MODTRAN, the atmospheric attenuation calculation module was developed to correct the atmospheric attenuation factors. Finally, the equivalent analysis of the simulated and actual measurements in the laboratory is carried out, and the irradiance of the equivalent space target is obtained. However, in the atmospheric attenuation process, it is still based on the more mature atmospheric attenuation calculation model. The main work is to continuously improve the atmospheric attenuation model or realize real-time or near-real-time acquisition of the atmospheric environment.

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