Modeling and Simulation of Space Target Optical Detection System

X.P. Du & H. Chen
Department of Space Equipment, the Academy of Equipment, Beijing, China
J.G. Zhao
Department of Scientific Research, the Academy of Equipment, Beijing, China

ABSTRACT: An optical detection system is built by using model building method based on the modulation transfer function. The effects of space environment and noise model have been considered and added in this system. In this model, we solve the establishment of the complex imaging model problem in dynamic running environment. Besides, this system can meet the demand of different space target detection task and the performance of the different stages of life span parallel analysis and evaluation system. The numerical simulations are performed to check the validity and capability of the proposed optical detection system.
KEYWORD: Space target; Dynamic environment; Optical detection system

1 INTRODUCTION

Space target optical detection system detection performance depends not only on the system structure, parameters and related properties of bearing platform. More important with bigger difference among different tasks, the characteristics of bearing platform orbit, the target dynamic optical properties and effects of the space environment factors. Therefore, in the stage of the system's whole life, how to ensure the formation and give full play to its performance is becoming an important subject to research by the construction of system.
Performance analysis technology application development level and system to ensure the system efficiency has an important support role. However, as mentioned above, detection system which involves many factors, the system performance analysis technology is complex, many difficulties. In 1948, the americans saide modulation transfer function (modulate transfer function, MTF) is first applied in evaluation of TV camera system imaging quality [1]. With the development of a large number of relevant theoretical research and experiment, the MTF is widely used in image quality evaluation, in the aspect of space-based optical system performance evaluation has become a kind of measuring optical load in orbit is a comprehensive indicator of performance [2-3].

In this paper, we proposed a space environment effect equivalent method in space target optical detection system. The optical subsystem model, image sensor subsystem model, electronics subsystem model, noise model and the effect of space environment model are established in the proposed scheme. The experiment results show that our method can realize the dynamic operating conditions accurately describe the optical detection system performance.

The rest of the paper is organized in the following sequence. In Section2, the proposed model is introduced in detail. In Section3, numerical simulation results are carried out to verify the validity of the model. Concluding remarks are summarized in the final section.

2 SPACE TARGET OPTICAL DETECTION SYSTEM AND MODEL BUILDING

2.1 *Space target optical detection system MTF model*

Space target optical detection system generally consists of optical subsystem, detector subsystem, electronic subsystem of three main parts. The system is inevitably affected by its noise and external environmental factors when it works. Therefore, the model of the system itself, noise model and the space environment Equivalence model are necessary to build for the simulation analysis of dynamic operating environment space target optical detection system performance. In this paper, all simulation results are in a space target space-based optical detection system as an example.

Based on the optical subsystem, image detector subsystem and electronic subsystem in the optical detection system, the modulation transfer function model MTF_{sys} can be expressed as

© 2015. The authors - Published by Atlantis Press

$$\mathrm{MTF}_{sys}(\rho)=\mathrm{MTF}_o(\rho)\cdot\mathrm{MTF}_d(\rho)\cdot\mathrm{MTF}_e(\rho) \quad (1)$$

where MTF_o, MTF_d and MTF_e represent the optical subsystem modulation transfer function model, detector subsystem modulation transfer function model and electronics subsystem modulation transfer function model respectively.

The optical subsystem modulation transfer function mode MTFo can be expressed s

$$\mathrm{MTF}_o(\rho)=\mathrm{MTF}_{o1}(\rho)\cdot\mathrm{MTF}_{o2}(\rho)\cdot\mathrm{MTF}_{o3}(\rho) \quad (2)$$

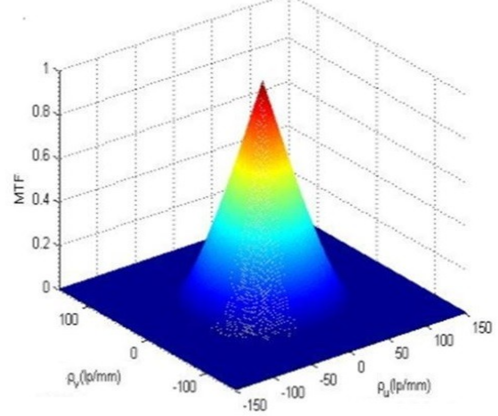
where $\mathrm{MTF}_{o1}(\rho)$, $\mathrm{MTF}_{o2}(\rho)$ and $\mathrm{MTF}_{o3}(\rho)$ are the diffraction limited system modulation transfer function model, non-diffraction limited system modulation transfer function model and assembly error modulation transfer function model, respectively.

The optical system adopts circular entrance pupil and its airy concentrated 83.78% of the energy in the incident in a round hole. The spread of the airy disk to cause a decline in the MTF, due to the diffraction limit systems does not exist on the exit pupil wave-front on ideal spherical aberration caused by deviation, is the ideal can achieve maximum MTF. The static MTF model can be written as [4-5].

$$MTF_{o1}(\rho)=\frac{2}{\pi}\left[\arccos\left(\frac{\rho}{\rho_c}\right)-\left(\frac{\rho}{\rho_c}\right)\sqrt{1-\left(\frac{\rho}{\rho_c}\right)^2}\right](\rho\le\rho_c) \quad (3)$$

where $\rho=\sqrt{\rho_u^2+\rho_v^2}$ is the spatial frequency and $\rho_c=\dfrac{D}{\lambda f}=\dfrac{1}{\lambda F_{\#}}$ denotes the cut-off frequency of the space optical system. Where D and f are the pupil diameter and force length of the optical system. λ represent the average wavelength.

According to the response spectrum analysis system, focal length, the diameter of the pupil, space and cut-off frequency, the 3D graph of the optical system diffraction limit the MTF model and its 2D layout are shown in Fig.1.



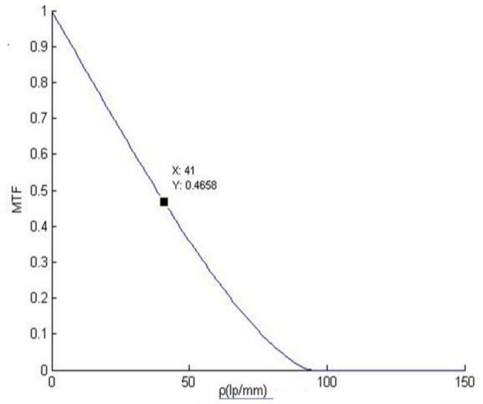


Figure 1. The 3D graph of the optical system diffraction limit the MTF model and its 2D layout.

For the non-diffraction limited system modulation transfer function model, the expression can be written as

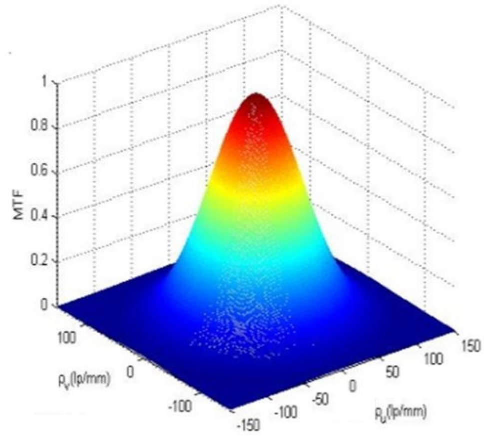
$$MTF_{o2}(\rho)=\exp\left[-2\pi^2\sigma^2\rho^2\right]=\exp\left[-b\rho^2\right] \quad (4)$$

where $b=2\pi^2\sigma^2$ is the dispersion parameters.

When the frequency is the Nyquist frequency, $\rho=\rho_{nyq}=1/(2d)$, the MTF model can be expressed as

$$MTF_{o2\_nyq}(\rho_u,\rho_v)=\exp\left[-0.77(B/d)^2\right] \quad (5)$$

The 3D graph of the optical system non-diffraction limit the MTF model and its 2D layout are shown in Fig.2.



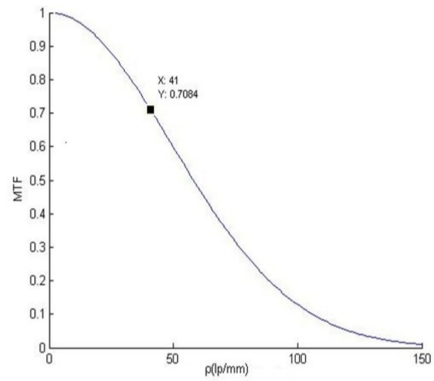


Figure 2. The 3D graph of the optical system non-diffraction limit the MTF model and its 2D layout.

2.2 *The effect of space environment equivalence analysis and model building*

Space-based space target optical detection system work in outer space environment, space a variety of natural environmental factors and the bearing platform vibration, attitude change, and the relative movement between target dynamic operating environment factors such as all affect the performance of optical detection system, which affects the quality of optical imaging. Therefore, in order to make sure the system imaging effect, must analyze the detection system of space environment effect.

3 OPTICAL DETECTION SYSTEM PERFORMANCE ANALYSIS INFORMATION GENERATED

Performance analysis information generated technology involves the dynamic optical characteristics of space target model, the dynamic optical imaging detection system running environment model, space model, the effect of space environment model, etc., according to the space target, optical detection system, the change of the space environment, such as real-time performance analysis information.

The optical detection system work as follow steps. First of all, based on the detection task, using the dynamic optical characteristics of space target model superposition sky background model, target time domain image generated task, carry on the fast Fourier transform, get the task frequency domain image. Using the space target optical detection system model for frequency domain image processing task goals, get the task frequency domain degraded images (image processing of the detector output without noise model simulation), Fourier inverse transformation, and the noise model processing, image output performance analysis (detector output simulation image).

4 CONLUSION

Equivalence in space-based optical detection system space environment effect analysis, at present in view of the space remote sensing camera to equivalent equivalent modulation transfer function (MTF) of the model analysis has begun to research. To focus on image motion and away from the focal analysis and based on MTF model, space-based space target of optical imaging system and space composition, structure and working principle of remote sensing camera is put in bigger difference, the working process of the optical imaging system in the space environment effect of the system also has particularity. In this paper, from the space of the ability of the target optical detection system is put forward to high dynamic space running environment from the effects on the optical imaging system due to coke, like to move, vibration and noise, established the equivalent model of the modulation transfer function (MTF). We Proposed task-oriented performance analysis information quickly generate method, can according to the mission, generated can satisfy the system in each stage of the whole life and all kinds of information required by each subsystem performance analysis, effectively solve the optical detection system based data source problem of the lack of performance analysis. Some numerical simulations have been performed for testing the validity of the proposed model.

REFERENCES

[1] Dan D. Influence of Outer Space Radiation on MTF of the Infrared Imaging System. Electronic Sci & Tech. 2010; 4: 4-6.

[2] Wang Q, Li X, Li X, Tang L. A Research on MTF for On——orbit Estimation and Accuracy Analysis Based on Three-bar Method. Theoretical research. 2011; 1: 14-21.

[3] Guo S, Mai Y, Qian X, Zhao H. A MTF calculation method of imaging system based on radial target field. China Science Paper. 2013; 8(4): 287-290.

[4] Wan C, Tong S. Analysis on testing principle for modulation transfer function of CCD camera. Semiconductor Optoelectronics. 2002; 23(1): 40-43.

[5] Harrison DC. Chow JC. Space-based visible sensor on MSX satellite. SPIE, 1994, 2217: 377-387.