Infrared Physics & Technology 77 (2016) 16–20

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Regular article

Analysis of the restricting factors of laser countermeasure active detection technology

Yufa Zhang *, Xiaoquan Sun

State Key Laboratory of Pulsed Power Laser Technology (Electronic Engineering Institute), Hefei 230037, Anhui Province, China

HIGHLIGHTS

- The mathematical model of cat eye target detection distance is built.
- Various parameters constraint detection performance is simulated.
- Appropriate laser parameters can be selected to achieve optimal detection effect.

ARTICLE INFO

Article history:
Received 22 October 2015
Revised 13 May 2016
Accepted 13 May 2016
Available online 14 May 2016

Keywords:
Cat-eye effect
Retro-reflected power
Region detection

ABSTRACT

The detection effect of laser active detection system is affected by various kinds of factors. In view of the application requirement of laser active detection, the influence factors for laser active detection are analyzed. The mathematical model of cat eye target detection distance has been built, influence of the parameters of laser detection system and the environment on detection range and the detection efficiency are analyzed. Various parameters constraint detection performance is simulated. The results show that the discovery distance of laser active detection is affected by the laser divergence angle, the incident angle and the visibility of the atmosphere. For a given detection range, the laser divergence angle and the detection efficiency are mutually restricted. Therefore, in view of specific application environment, it is necessary to select appropriate laser detection parameters to achieve optimal detection effect.

1. Introduction

Optoelectronic countermeasure active reconnaissance can be carried out by the cat eye effect which comes from the optical system of the photoelectric equipment. i.e. the photoelectric equipment reflects the incident laser beam to the direction of laser emitter. Furthermore, the echo power of cat eye target is usually 10^2–10^4 times higher than the power reflected by ordinary diffuse target. Therefore, the power is available for capturing the optoelectronic devices effectively. However, laser active detection effect is restricted by various kinds of factors.

The existing research on cat eye echo power is focused on laser emitter and cat eye reflection, and there is little research on laser region detection. Zhao and Zhang had analyzed the impact factors on echo power based on the theory of geometric optics [1,2], the reflection characteristics of cat eye lens had been studied from the perspective of physical optics by Ma and Zhao [3,4]. Using experimental method, the echo power of cat eye target had been detected by Liu and Zhou [5,6]. With the in-depth study and expanded application, laser active detection system is updating to high efficiency and miniaturization. Furthermore, various kinds of complex application environment demand laser active detection system upgrading techniques.

In this article, the laser active detection technology based on cat eye effect is studied, and the echo power formula is deducted. Meanwhile, echo characteristic of cat eye target compare to the echo characteristic of diffuse target is analyzed. Also, the discovery distant of laser active detection system is presented. The hinge relationships between the divergence angle and the region area of detection distance are studied. The reasonable parameters of laser active detection are analyzed deeply, and the relationship between detection efficiency and laser parameters is summarized.

2. Physical model of laser active detection

The cat eye effect of vast majority of optical devices is available for the application of active laser detection technology [7–9]. When photoelectric equipment is in the field of view of laser emitter, the strong laser echo signal can be used to distinguish the cat

* Corresponding author.
E-mail address: zyf9180@163.com (Y. Zhang).

http://dx.doi.org/10.1016/j.infrared.2016.05.014
1350-4495/

eye target from the diffuse background clearly. According to the detection of the echo power, cat eye target can be found and its principle is shown in Fig. 1.

The characteristic of cat eye effect is that the light exposed to the optical window of cat eye system will be reflected to the direction of laser emitter. Therefore, the laser detector is usually placed at the laser emitter. That is, after the laser irradiation from A to B in the range of R, the laser echo signal will be returned to A. However, Laser echo power is affected by the laser emission system, detection system, cat eye target system and other parameter such as atmospheric transmission [10,11].

In order to facilitate the analysis, we assume that laser energy distributes evenly and the characteristic of atmosphere is isotropy. The transmission of laser in atmosphere is assumed to conform to the principle of geometrical propagation. The spot size of the laser formed at B can be expressed as:

$$S_1 = \pi(R\tan(\theta_t/2))^2 \approx \pi R^2\theta_t^2/4 \tag{1}$$

where θ_t describes the laser divergence angle.

The spot size of the retroreflected laser formed at A can be expressed as:

$$S_2 = \pi(R\tan(\theta/2))^2 \tag{2}$$

where θ is the divergence angle of the reflected laser.

Laser power received by optical window at B is given by,

$$P_{rB} = (P_t\tau_t\tau/S_1)A_s\tau_s \tag{3}$$

P_t denotes the power of laser, and τ_t is the transmittance of laser emitting system. τ is horizontal atmospheric transmittance of laser. The transmittance of cat eye system is τ_s, and A_s is the optical window area of cat eye system. Laser power reflected by the cat eye target can be expressed as

$$P_{tB} = P_{rB}\tau_s\rho = P_tA_s\rho\tau_t\tau\tau_s^2/S_1 \tag{4}$$

where ρ is the reflectivity of cat eye target.

Due to the reflection of cat eye target, laser echo power can be expressed as

$$P_{r0} = 16P_t\frac{A_sA_r\rho\tau_t\tau_r\tau_s^2\tau^2}{\pi^2\theta_t^2\theta^2R^4} \tag{5}$$

where A_r is the optical window area of laser echo receiving system. τ_r is the transmittance of detection system [12], and τ^2 is dual laser atmospheric transmittance, V denotes the visibility.

$$\tau^2 = \exp\left[-3.912\left(\frac{\lambda}{0.55}\right)^{-q}2R/V\right] \tag{6}$$

Usually, there is a certain incident angle when the incident light exposed to cat eye system in the process of active laser reconnaissance based on cat eye effect. So, the laser receiving area of cat eye target is not the real area of optical system [13], and the effective receiving area of cat eye system can be expressed as,

$$A_s = \frac{D^2}{2}\arccos\frac{2f\tan\theta}{D} - 2f\tan\theta\sqrt{\frac{D^2}{4} - (f\tan\theta)^2} \tag{7}$$

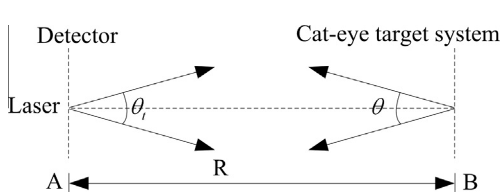

Fig. 1. Echo power model.

When the cat eye optical system assembled perfectly, $\theta_t = \theta$. The echo power received by detection system at A is given as follow,

$$P_{r0} = 16P_t\frac{A_sA_r\rho\tau_t\tau_r\tau_s^2\tau^2}{\pi^2\theta_t^4R^4}\cos\alpha \tag{8}$$

where α describes incident angle.

According to (8), when the active laser detection system is in operation, laser echo power is affected by laser emission system, optical system of cat eye target, echo receiving system and atmospheric properties and other factors.

Because of the large field of view is concerned in laser reconnaissance commonly, and the background is usually considered as diffuse large target, so the laser echo power of background is determined by the characteristics of diffuse reflection,

$$P_{r1} = \cos\alpha\cdot P_t\tau_t\tau_rA_r\tau^2\rho_2/(\pi R^2) \tag{9}$$

In terms of echo power, the premise on distinguishing cat eye target and diffuse reflection target is the difference of echo power reflected by two kinds of targets in the same system parameters and application environment. That is $P_{r0}/P_{r1} = \frac{16A_s\rho\tau_s^2}{\pi\theta_t^4R^2\rho_2} > 1$. Therefore, the discovery distance of active laser detection system can be expressed as: the maximum distance that the echo power of cat eye target is greater than the echo power of background.

3. The simulation of discovery distance

According to the analysis above, the detection ability of laser active detection system is related to many factors such as laser divergence angle, incident angle, reflectivity and atmospheric visibility. Parameters for simulation are stetted as follows: The laser power is 3×10^6 W, the transmission of laser emission system is 0.9, divergence angle of laser is 5 mrad, and wave length is 1.06 μm. The atmospheric visibility is 20 km and q = 1.6. The diameter of cat eye target is 10 cm, the focus is 20 cm, and the transmission is 0.9, the reflectivity of cat eye system is 0.07. The transmission of laser detection system is 0.9, and the diameter of receiving optical window is 10 cm. The diffuse reflectivity is 0.02.

3.1. Effect of detection distance on echo power

The echo power of cat eye target and background vary with the distance at normal incidence is plotted in Fig. 2.

It can be seen from Fig. 2 that the echo power of optical target decreases gradually and the power close to the echo power of diffuse reflection target when detection distance increases accordingly. According to the simulated results, we can conclude that

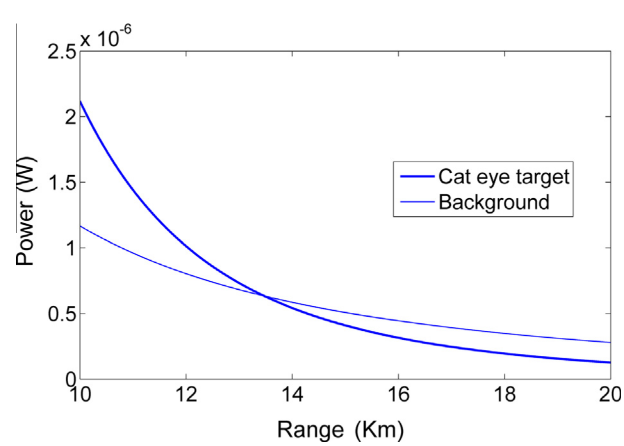

Fig. 2. Variation of echo power with detection distance.