Stealth technology by weakening the laser echoes

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Abstract: Aiming at the detection threat on photoelectric equipment caused by active laser detection technology, the stealth technology by weakening the "cat′s eye effect" was studied in this paper. Take the night vision objective lens as an example, the stealth technology was studied quantitatively by means of matrix optics tracing, and was proved by experiments. The results show that the echo intensity of the "cat′s eye effect" was affected easily by reconnaissance environment and system assembly errors, such as the tilt and the defocus of photosensitive surface. Thus, under the premise of the limited change optical structure of photoelectric devices and the reduction of their image quality, some assembly errors created artificially can weaken the "cat′s eye echo" of the system, so as to achieve stealth. This technology can effectively reduce the probability of being detected and attacked by the enemy in military confrontation, so it has certain reference value in the military.

Key words: stealth technology; echo; cat′s eye effect; matrix optics

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减弱激光回波的隐身技术

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摘 要:针对激光主动探测技术对光电装备造成的探测威胁,提出了一种基于减弱“猫眼效应”的隐身技术。以夜视仪物镜为例,运用矩阵光学追迹法对这种隐身技术作定量分析,并用实验进行验证。研究结果表明:“猫眼效应”回波强度容易受到侦察环境和系统装配误差等因素的影响,例如:光敏面倾斜、离焦。因而,在有限改变光电设备光学结构及降低成像质量的前提下,人为地的制造一些“装配误差”可以减弱系统的“猫眼效应”,从而达到隐身的目的。这一技术能有效减少自身在军事对抗中被敌方侦察打击的概率,具有一定的军事参考价值。

关键词:隐身技术; 反射; “猫眼效应”; 矩阵光学

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0 Introduction

Active laser reconnaissance technology is a new way for military operation. It includes reconnaissance detection, location and identification of photoelectric equipments by laser beam.

The laser beam emitted by scanning device "S" irradiate in the optical system firstly, through equivalent lens "L" and converge on the photosensitive surface "P", and reflected by "P", through the objective "L" once again and is received by the echo detector "J" finally. The optical path is known as the "cat's eye reflected light" which enables the reflected light to return along the incidence direction. The background echo's energy intensity of clouds and atmospheric is comparatively weak, while the energy intensity of "cat's eye" reflection produced by the optical system to be detected is very strong. The echo energy difference is the mainly basis of the active laser detection device for detecting the position of photoelectric equipment.

1 Review

At present, the active reconnaissance technology has been applied to various types of laser reconnaissance warning system in the United States and other developed Western countries. There are a number of research and application in our country[1-3].

There are many scientific researches on the "cat's eye effect" applied in laser reconnaissance, which mainly discuss the active reconnaissance based on high energy laser echo produced by the "cat's eye effect", while less discussion is given to the technology on how to effectively weaken the "cat's eye effect" so as to achieve their own stealth. Therefore, it is of great significance in military confrontation on how to weaken the "cat's eye" effect and to achieve effective stealth in the premise of the limited change internal structure of photoelectric device and the reduction of their image quality.

This paper quantitatively analyzes the influencing factors of "cat's eye effect" by the matrix optics tracing method[4], based on the objective lens of the night vision devices. The results have important reference value for the applicable scope of laser reconnaissance technology.

2 Methodologies

2.1 Ray tracing

According to the matrix optics[5], objective lens's refracting surface, optical spacing and reflection of the infrared detector can be expressed as matrixes of **R**, **T** and **F** in Fig.1.

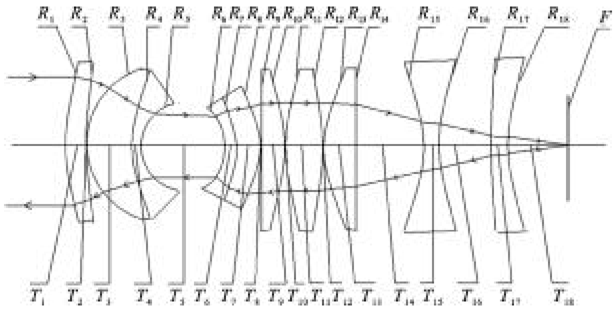

Fig.1 Configuration of the night vision objective lens

$$\mathbf{R}=\begin{bmatrix}1 & 0\\ -(\mathbf{n}_2-\mathbf{n}_1)/\mathbf{r} & 1\end{bmatrix},\ \mathbf{T}=\begin{bmatrix}1 & \mathbf{d}/\mathbf{n}\\ 0 & 1\end{bmatrix},\ \mathbf{F}=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}$$

Where **n** is refractive index of optical interval; $\mathbf{n}_1$ and $\mathbf{n}_2$ are the refractive index of the front and after surface refractive lens respectively; **r** is the radius of curvature of the refractive surface; **d** is the thickness of optical interval. The above parameters are from Handbook of optical lens[6].

In the ideal case, scanning laser works in optical system, transmitting from left to right, refracting, reflecting and finally reaching the surface $\mathbf{R}_{18}$, which can be expressed by matrix $\mathbf{M}_1$:

$$\mathbf{M}_1=\mathbf{R}_{18}\mathbf{R}_{17}\mathbf{T}_{17}\mathbf{R}_{16}\mathbf{T}_{16}\mathbf{R}_{15}\mathbf{T}_{15}\mathbf{R}_{14}\mathbf{T}_{14}\mathbf{R}_{13}\mathbf{T}_{13}\mathbf{R}_{12}\mathbf{T}_{12}\mathbf{R}_{11}\mathbf{T}_{11}\mathbf{R}_{10}\mathbf{T}_{10}\cdot \mathbf{R}_9\mathbf{T}_9\mathbf{R}_8\mathbf{T}_8\mathbf{R}_7\mathbf{T}_7\mathbf{R}_6\mathbf{T}_6\mathbf{R}_5\mathbf{T}_5\mathbf{R}_4\mathbf{T}_4\mathbf{R}_3\mathbf{T}_3\mathbf{R}_2\mathbf{T}_2\mathbf{R}_1\mathbf{T}_1$$

The laser is reflected by the photosensitive surface **F**, transmitting from right to left, through each lens along with the opposite direction of the incident, shooting from the optical system finally. Similarly, the process can be expressed by matrix $\mathbf{M}_2$:

$$M_2=R_1T_1R_2T_2R_3T_3R_4T_4R_5T_5R_6T_6R_7T_7R_8T_8R_9T_9R_{10}T_{10}R_{11}T_{11}R_{12}T_{12}R_{13}T_{13}R_{14}T_{14}R_{15}T_{15}R_{16}T_{16}R_{17}T_{17}R_{18}$$

If the incident light matrix is L_i, then the emergent light matrix is L_o:

$$L_o=M_2T_{18}FT_{18}M_1L_i \tag{1}$$

2.2 Echo energy estimating

Under certain conditions, the intensity of light in the beam cross section is proportional to the energy of the beam carrying.

Supposing "detector receives light ratio η" is the ratio of the amount of light reflected from the optical instruments and received by the echo detector "J" to the total amount of light entering the optical instrument, and atmospheric transmittance, lens transmittance, reflector reflectivity can be obtained, then the η can estimate the intensity of laser echo received by echo detector "J"[7].

2.3 Calculation results analysis

There are many influencing factors of "cat's eye effect", such as the intensity and the incident angle of scanning laser beam, the relative aperture and the field of view of the optical system detected, the tilt of camera tube target surface, defocus, area and reflectance etc. In addition, the optical system has such aberrations as spherical aberration. The spherical aberration varies with the incident angle of incident light and produces similar echo with that of reflector's tilt.

Supposing the distance "D" between the active laser detection device and the nightvision objective lens is 1 000 m, and scanning laser beam consists of 10 000 parallel lights which uniform distribute in the cross section and cover the effective aperture of optical system, and the effective size of echo detector "J" is 1 m, then, the echo intensity can be calculated by formula(1) as the following conditions: the incident angle change from 0 rad to 0.50 rad, the reflector of infrared detector defocused (defocusing amount Δ is ±0.1 mm) and inclined (inclination θ is 5′), the presence of spherical aberration, the relative aperture "Ö" changes from 1:4 to 1:8 etc. The calculations are shown in Table 1.

The calculations show that such factors as defocusing, incline and changes in the relative aperture influence the η greatly. When the incident angle increases to 0.4 rad, the η equals to 0, the detector is basically impossible to detect laser echo. Therefore, within certain limits, to take advantage of these factors weaken the "cat's eye effect" can achieve stealth for photoelectric device detected.

Tab.1 Ratio η changes with defocusing, incline, spherical aberration and relative aperture

Angle of incidence/rad	Relative aperture of object lens: Ö=1:2					Δ=0 mm	
	η_1/% (Δ=0 mm)	η_2/% (Δ=0.1 mm)	η_3/% (Δ=-0.1 mm)	η_4/% (θ=5′)	η_5/ % spherical aberration	η_6/% (Ö=1:4)	η_7/% (Ö=1:8)
0.00	100.00	8.61	7.14	11.64	13.14	67.32	39.46
0.10	77.54	6.06	5.12	7.11	6.76	45.23	9.98
0.20	34.65	1.72	0.53	0.23	0.76	12.76	0.00
0.30	20.03	0.00	0.00	0.00	0.00	0.00	0.00
0.40	7.87	0.00	0.00	0.00	0.00	0.00	0.00
0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3 Experiments

In the experiment the semiconductor laser of which wavelength is 0.63 μm, the beam radius is 6 mm, the divergence angle is 1 mrad, is used to scan a telescope. The echoes form spot images on the receiving screen of 2 m distance, the CCD detector is used to record its strength, and then the echo images and its intensity distribution can be obtained as shown in Fig.2. In addition, the echo detection rate of telescope can be obtained according to the scanning laser intensity, the received echo's intensity and the background echo's intensity[8]. The calculations are shown in Tab.2.

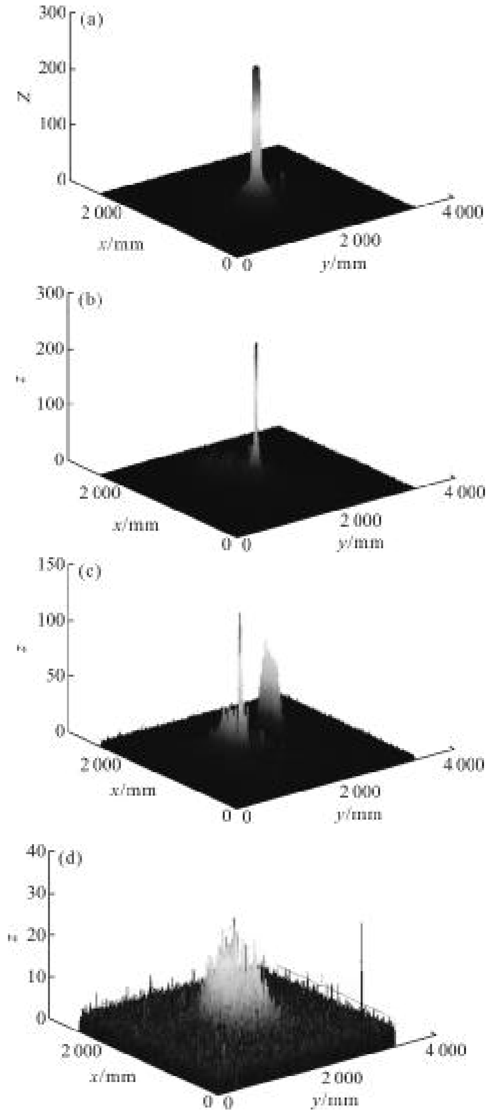

Fig.2 Intensity distribution of laser echo

Tab.2 Influence of defocusing, incline on echo ratio of active detection

Angle of incidence is 0 rad	Defocusing			Incline
	Δ=0 mm	Δ=0.1 mm	Δ=-0.1 mm	θ=5′
Echo ratio/% (**D**=2 m)	95.03	30.51	28.34	46.43
Echo ratio/% (**D**=4 m)	74.45	22.12	15.32	21.75

From the experimental results, when the scanning laser parallels incidenting, the spot's intensity is strong with regular shape, which is actually the "cat's eye effect", as shown in Fig.2(a). When the photosensitive surface is defocused, the bright spot's intensity becomes weaker and its shape changes, as shown in Fig.2(b). When the photosensitive surface tilts and the incident angle exceeds 0.1 rad, then the spot's intensity of "cat's eye" reflection decreases rapidly, until disappears, as shown in Fig.3(c)-(d). The defocusing and incline influence the echo ratio greatly as shown in Tab.2. These experimental results are in accordance with the previous theoretical conclusions.

4 Conclusions

This research indicates that the echo intensity of the "cat's eye effect" is affected easily by reconnaissance environment and system assembly errors, such as the tilt and the defocus of photosensitive surface. Thus, under the premise of the limited change optical structure of photoelectric devices and the reduction of their image quality, some assembly errors created artificially can weaken the "cat's eye echo" of the system, and can effectively reduce the probability of being detected and attacked by the enemy in military confrontation.

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