Model and Analysis of Target Detection Probability under Strong Background Light

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***Abstract*—**In order to improve the target detection performance of the photoelectric imaging system under strong background light, it is necessary to establish the probabilistic assessment model of the photoelectric imaging system. According to the target surface luminous flux function, obtains the target radiation illumination, in accordance with the formula of Purcell, calculates the brightness of the background radiation, according to the relationship among the signal to noise ratio of the detector, the false alarm probability and the detection probability, deduces the target detection calculation model of the photoelectric imaging system under strong background light. Through the calculation and analysis, gives the functional relationship of the target's radiation illumination and working distance at different angles of incidence, gets the curves of signal to noise ratio and the time of signal stranded detector in a certain false alarm probability, verifies the computational model of the target detection probability of the photoelectric imaging system under strong background illumination.

***Keywords*—**radiation illumination, signal to noise ratio, false alarm probability, detection probability.

I. INTRODUCTION

THE photoelectric imaging optical system mainly composed of optical lens, imaging CCD, image processing module and processing circuit. Its purpose is to capture the spatial target imaging information, mainly uses in aerospace, navigation and weapons development, can also be used in the daily traffic control, production workshop or testing and other environments, the photoelectric imaging optical system is mainly visible and infrared as the core of the photoelectric imaging acquisition. Based on the detection of visible light background, the sensitivity of the optoelectronic imaging device depends on the target brightness in the environment and the contrast of the detection system, the change of the environment causes the change of the target brightness, thus affects the sensitivity of the photoelectric imaging system. Many factors will impact optical imaging system detection performance in the strong background environment, such as, the radiation characteristics of the target itself, the ambient illumination, the responsiveness of the photoelectric imaging sensor, these factors restrict the improvement of the optical imaging system, especially under the low illumination of the photoelectric detection capability is obviously insufficient. Therefore, it is necessary to study the new objective optical properties calculation model, establish the contribution theoretical calculation model of the target optical properties to the photosensitive surface of the photoelectric imaging detection sensor with different distance and background illumination, which provides important theoretical basis for target detection, monitoring and parameter calculation under strong background light.

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II. MODEL OF TARGET DETECTION CAPABILITY

The detection capability of the target of the photoelectric imaging system is evaluated by the signal to noise ratio, which is defined as the ratio of the detector output signal to the root mean square of the detection noise [1]-[2]:

$$S_{NR} = I_0 \Big/ \sqrt{I_a} \tag{1}$$

In the equation (1), I_0 is the current value of the signal on the single detector, I_a is the root mean square of the noise current on the single detector.

Assuming that the target signal is concentrated on a single pixel of the detector, the signal to noise ratio of the detector can be expressed by the number of photons, then the number of photons of the target signal is:

$$G = \psi_0 \cdot \mathrm{A}_S \cdot \kappa_M \cdot \eta_S \cdot \tau_0 \cdot (t_2 - t_1) \tag{2}$$

CCD detector receives the background signal corresponding to the number of photons:

$$B = \psi_b \cdot \mathrm{A}_S \cdot \kappa_b \cdot \eta_b \cdot \tau_0 \cdot (t_2 - t_1) \cdot \beta^2 \tag{3}$$

The number of photons corresponding to the noise generated by the ambient background signal is:

$$G_b = \sqrt{\psi_b \cdot \mathrm{A}_S \cdot \kappa_b \cdot \eta_b \cdot \tau_0 \cdot (t_2 - t_1) \cdot \beta^2} \tag{4}$$

Where: ψ_0 is the signal photon flux on a single pixel, A_S is the detector receiving area, κ_M is the filter coefficient of the system to the target signal, η_S is the average quantum efficiency of the detector to the signal, τ_0 is the optical system transmittance , t_1 is the time when the signal enters the detector, t_2 is the time when the signal leaves the detector, ψ_b is the photon flux of the background signal, κ_b is the filter coefficient of the background signal of the system, η_b is the average quantum efficiency of the detector against the background signal, β^2 is a single pixel area.

According to equations (3) and (4), the signal to noise ratio of formula (1) can be expressed as:

$$S_{NR} = \frac{B/q^2}{G_b} = \frac{\psi_b \cdot \mathrm{A}_S \cdot \kappa_b \cdot \eta_b \cdot \tau_0 \cdot (t_2 - t_1) \cdot \beta^2}{q^2 \cdot \sqrt{\psi_b \cdot \mathrm{A}_S \cdot \kappa_b \cdot \eta_b \cdot \tau_0 \cdot (t_2 - t_1) \cdot \beta^2}} \quad (5)$$

In the formula (5), q^2 is a single pixel corresponding to the target surface area.

Since the detection probability is calculated under a certain false alarm probability, in order to ensure a high detection probability, it is necessary to meet the detection probability of a certain false alarm probability and detector signal to noise ratio:

$$P(S_{NR}) = \frac{1}{\sqrt{2\pi}} \int_{S_{NR}-T_{NR}}^{\infty} \exp(-\frac{t^2}{2}) dt \quad (6)$$

In the equation (6), T_{NR} is the false alarm probability.

III. Model And Analysis Of Target Optical Characteristics

The system does not provide additional light source, the target itself does not light, mainly rely on the reflection of visible light, the target and the visible light spectral characteristics of the same, the radiation brightness from visible radiation, Assuming that the spectral irradiance of visible light is, the visible light radiation received by the target panel dS is [3]:

$$\Psi_1 = \int_\lambda E(\lambda) dS \cos\theta d\lambda \quad (7)$$

In the formula (7), θ is the angle between the normal of the target bin and the incident angle of the visible light. Assuming that the diffuse reflection coefficient of the target bin is $\zeta(\lambda)$, the luminous flux of the target bin is [4]:

$$\Psi_2 = \int_\lambda \zeta(\lambda) E(\lambda) dS \cos\theta d\lambda \quad (8)$$

Assuming that the bin is a fully extended surface, the light flux on the receiving surface dS' at a distance H from the receiver's receiving surface normal to the direction of ω is [5]-[6]:

$$\Psi = \frac{\cos\omega}{\pi} \int_\lambda \zeta(\lambda) E(\lambda) dS \cos\theta d\lambda \cdot dS' \cdot \frac{1}{H^2} \quad (9)$$

According to equation (9), the irradiation area is integrated to obtain the target irradiance [7]-[8]:

$$E_j = \frac{\zeta E_1}{\pi H^2} \int_S \cos\omega \cdot \cos\theta dS \quad (10)$$

In the formula (10), E_1 is the illuminance of visible light reaching the ground.

The target shape usually consists of a plane, a sphere, a cylinder, and a cone, so the target to ground illumination can be expressed as:

$$E_n = \sum_j E_j \quad (11)$$

IV. The Characteristics Of Environmental Background

Environmental background Light is the combined result of the atmospheric light around the Earth on the sunlight, the scattering and refraction of the reflected light on the ground, and the brightness varies with the zenith, time, and the angle with the sun.

Atmospheric optics provided information shows that the brightness of sunny weather background light changes generally $0.3-0.7sb$, brightness with the angle between the sun and the sun varies, high angle of the sun, the angle is small, the brightness increases. The general sunny background light to short band based, peak wavelength in the $500-650nm$ range.

Generally, the background brightness of the sky is expressed as magnitude and the apparent magnitude of the same space object [9]. It is known that the magnitude K_1, K_2 and the brightness N_1, N_2 of two targets are known according to the formula (12):

$$K_2 - K_1 = -2.5 \lg \frac{N_2}{N_1} \quad (12)$$

By celestial photometry results that the atmosphere outside the square every degree of 0^k stars such as the brightness of the $0.97 \times 10^{-6} sb$, you can convert the ambient background brightness in $0.3-0.7sb$ corresponding to the magnitude of stars.

In order to facilitate the calculation and expression of the ambient background light, for the sunny day background, μ, ϖ and σ represent the ambient brightness at any point of the environment as $N_{xy}(\mu_x, \mu, \varpi)$, and the corresponding background brightness expression is [10]:

$$\frac{N_{xy}(\mu_i, \mu, \varpi)}{N_{zxy}(\mu_i)} = \frac{\varphi(\mu) \cdot \rho(\varpi)}{\varphi\left[\frac{\pi}{2}\right] \cdot \rho\left[\frac{\pi}{2} - \mu_i\right]} \quad (13)$$

In equation (13), the target elevation angle μ is the target azimuth angle σ, μ_i is the solar elevation angle and azimuth angle, ϖ is the included angle between the target and the sun, $N_{xy}(\mu_i, \mu, \varpi)$ is the ambient background brightness at the desired location, $N_{zxy}(\mu_i)$ is sunny day top brightness, in units of cd/cm^2.

V. Calculation And Analysis

According to the target's radiation characteristics under strong background light and environmental background characteristics, the target detection probability calculation function is deduced. Assuming a target length of 300mm, a diameter of 100mm, an optical lens focal length of 200mm, an optical lens transmission of 0.85, photo detection receiver light-sensitive surface is $400mm*400mm$, and a response wavelength of $400-750nm$, the quantum efficiency of the detector is 0.88. According to equation (5), we can calculate the signal to noise ratio and signal retention detector time curve, shown in Figure 1.

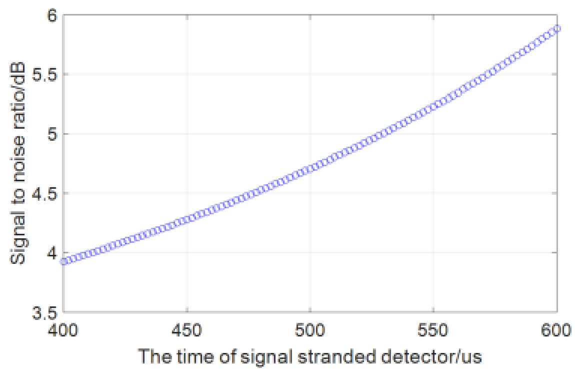

Figure 1. The curve of signal to noise ratio and time of signal stranded detector

From Figure 1, the monotonically increasing function of signal to noise ratio versus signal stranded detector time increases with increasing residence time, indicating that the speed of the target through the detector is inversely proportional to the residence time.

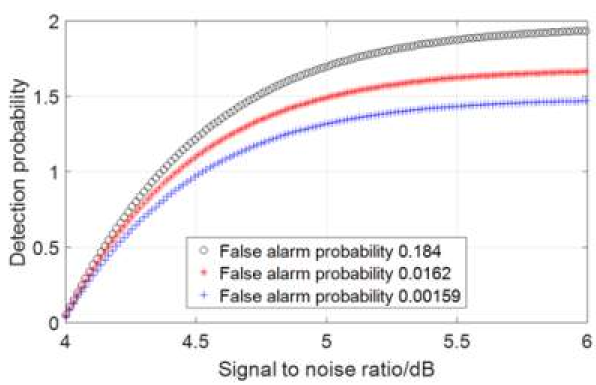

Figure 2. The curve of detection probability and signal to noise ratio of detector

According to the formula (6), we get the curve of the detection probability and the signal to noise ratio of the detector under a certain false alarm probability, as shown in Figure 2. It can be seen that the detection probability and detector signal-to-noise ratio curve showed a nonlinear trend, with a certain false alarm probability, as the detector signal to noise ratio increases, the detection probability is greater, and the detector signal to noise ratio in certain circumstances, the higher the false alarm probability, the greater the probability of detection.

Taking into account the target at different detection distances, the target in the detection area of the target characteristic irradiance changes with the detection range changes, according to the formula (9) and (10), Figure 3 shows the curve of target luminous flux and working distance when target take into the detection area at different angles of incidence, Figure 4 shows the curve of the target radiation illumination and working distance when the different light source wavelengths.

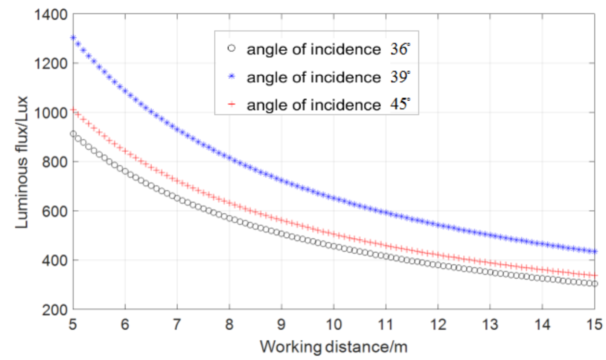

Figure 3. The curve of target luminous flux and working distance

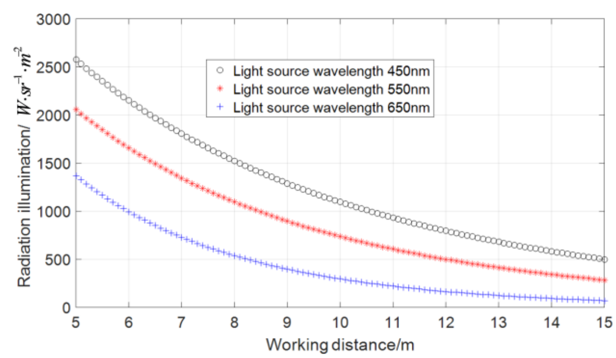

Figure 4. The curve of the target radiation illumination and working distance

It can be seen from Figure 3 and Figure 4 that the farther the working distance is, the smaller the radiation irradiance sensed by the detector is at the same target size, indicating that the farther the working distance is, the smaller the radiation flux of the target surface to the photoelectric imaging system, Detection capability is also reduced. The same working distance, the target surface area, the target surface of the radiation energy on the photo detection system, the greater the contribution of radiation energy, the detector the greater the target radiation flux, help to improve the target detection capability.

VI. Conclusion

This paper studies the calculation model of target detection probability of optical imaging system, analyzes the information of environment background characteristic and target radiation which is radiated to the detection receiving system, deduces optical imaging system target detection probability calculation model under strong background from the relationship among signal to noise ratio, false alarm probability, detection probability of the detector. The paper gives functional relationship between the target radiation irradiance and detection distance at different angles of incidence, and meanwhile, givens the curve of the target detection probability and the signal-to-noise ratio of the detector under certain false alarm probability. The probabilistic calculation model established in the paper provides a scientific and reasonable basis for improving the target detection rate in the photoelectric imaging system under strong background light.

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