Target Detection Ability Calculation method in Target Tracking System

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Abstract
To improve the tracking performance in photoelectric tracking system, this paper researches target detection ability calculation method. according to the principle of photoelectric tracking system, optoelectronic properties of photoelectric detection system was analyzed, and the model of optoelectronic properties of target was set up, the instantaneous electric current of CCD was deduced; based on the characteristics of the target luminance, background luminance and CCD noise, detection performance was analyzed and the output signal calculation method was given in photoelectric tracking system; the relation of limited detectable distance of the photoelectric detection system with the exposure time of CCD, the threshold of SNR and the dark current of the photoelectric detection system was discussed. Through the calculation and experiment analysis, the results show that within a certain illumination, the longer the exposure time of CCD is, the smaller the dark current of the photoelectric detection system is; the theoretical speed and the actual speed of control angle is basically consistent, which show the calculation method of target detection ability is correct.

Key words: PHOTOELECTRIC TRACKING, DETECTION PERFORMANCE, CCD, TARGET CHARACTERISTICS

1. Introduction

The photoelectric tracking system is the important equipment which captures the information of dynamic target. For the photoelectric tracking system, the tracking precision and reliability are restricted by the detection performance of the optical imaging detection system[1]. The system's detection performance is related to the detection performance of the optical imaging detector, the parameters and transmittance of optical lens, because of the complexity of the work environment, the variation of sky background brightness, the target's size, and so on. Especially, in underwater target detection system, target echo signal analysis and processing in practical engineering is an important research focus, with the increase of the complexity of the environment[2], the jamming signal processing effectiveness is becoming more prominent, especially marine underwater target signal processing effectiveness. In order to extract the target signals more accurately, it shouldn't always assumes that the jamming signal is Gaussian, and the target signal as a non-Gaussian noise.

In recent years, with the development of technology, target tracking and detection technology at home and abroad has made new breakthroughs[3,4]. Development and application of infrared technology in particular has the broad application prospect, which promote weapon guidance, infrared warning and real-time surveillance and other aspects of reform. Target tracking is a classical problem in computer vision, its basic task is to determine or estimate the position, velocity and effective features on interested targets of video sequences. In the civil context, the application of target tracking such as video coding, intelligent transportation and Video surveillance, provide oversight and supervision role for travel safety to avoid the occurrence of accidents[5]. In military applications, Target tracking is a key technology for reconnaissance target, intelligent control oriented, and data analysis.

To effectively improve the stability of the target tracking system, it needs to establish a suitable environment object tracking algorithm from the optical platform target tracking, research target detection ability calculation method to improve its detection capability.

2. The optoelectronic properties of photoelectric detection system

2.1 The principle of photoelectric tracking system

Photoelectric tracking system includes CCD, lens, image acquisition module and computer, rotational structure, the rotational angle, and so on. CCD main is gain target image information, image acquisition module main is store image under synchronous trigger, computer gather target image and dispose it by image processing techniques, Figure 1 is principle of photoelectric tracking system.

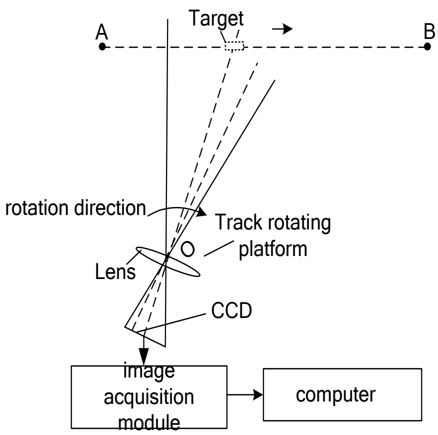

Figure1. The principle of photoelectric tracking system

In the whole process of the field test, the target tracking system is always in the center region view image. We use the high precision angle encoder to gain the rotational angle; this angle will be contrast to the result of theoretical arithmetic, and using the error to judge the effect of tracking.

2.2 Optoelectronic properties analysis

According to the design of photoelectric tracking system[6,7], in order to improve its detection sensitivity and performance, it needs to consider the optical and optoelectronic properties of CCD. According to CCD's working principle can know that it will produce minority carrier injection after adding to a positive voltage, the photons is aroused by the radiation recombination luminescence of minority carriers. But in certain conditions, the photon density determines the output power of CCD, for the CCD, it's important to determine the number of photons which is aroused by the radiation recombination of minority carriers. Because the CCD's photosurface area is mainly concentrated on the active region of detection area, it's the critical work to analyze the density of excess carrier and total photons of CCD active region, then proceed with the steady-state analysis for the rate equation.

$$I_{CCD} = \left[R_r(n) + R_n(n)\right] qV_{act} \quad (1)$$

$$h = \tau_{ph}\beta_{sp}R_r \quad (2)$$

n is the density of excess carrier of CCD's active region, V_{act} is the active region's volume, R_r is the net recombination rate of direct radiation of the detection area, R_n is its net recombination rate of composite center, I_{CCD} is the current of CCD, h is the density of total photons, β_{sp} is the CCD's Spontaneous coefficient, τ_{ph} is the photon lifetime. For CCD, non-radiative recombination mainly arises from the composite center, which is non-equilibrium carriers going through the forbidden band of E recombination centers for the capture compound into phonon, while the non-radiative also contains auger recombination. The net recombination rate in the recombination centers of CCD R_n can be calculated by

$$R_n = \frac{C_p C_t (N_0 + P_0 + n)n}{(N_0 + n_1 + n) + (P_0 + P_1 + P)/C_n} \quad (3)$$

In (3), $n_1 = n_i e^{\frac{E_t - E_i}{KT}}$, $p_1 = n_i e^{\frac{E_i - E_t}{KT}}$, C_n, C_p are the capture coefficients of the electrons and holes, C_t is interface trap density of states, E_t is recombination center energy level, E_i is intrinsic Fermi level, n_i is intrinsic carrier concentration. Assume $C_n = C_p = C$, $n_0 + n = p + p_0$, R_r is given as follows:

$$R_r(n) = \frac{2B_r n_i \exp\left[\frac{qV}{2k_0}T\right] \times \frac{I_{CCD}}{qV_{act}}}{2B_r n_i \exp\left[\frac{qV}{2k_0 T}\right] + CN_{t,\mathrm{CCD}}} \quad (4)$$

B_r is the composite coefficient of CCD's detection area, n_0, p_0 are the equilibrium electron and hole density, $N_{t,CCD}$ is interface trap density of states.

According to the $I - V$ characteristics of semiconductor, the $I-V$ characteristics of CCD can be deduced in photoelectric tracking system.

$$I_{CCD}=\frac{qn_i dCN_{t,\mathrm{CCD}}}{2}\exp\left[\frac{qV}{2kT}\right]+\frac{D_n}{L_n}\cdot\frac{n_i^2 q}{N_A}\exp\frac{qV}{kT} \quad (5)$$

Because the luminescence of CCD mainly comes from the diffusion current, while the non-radiative recombination mainly comes from the recombination current.

$$\frac{R_r(n)}{R_n(n)}=\frac{2n_i D_n}{L_n N_A dCN_t}\exp\left[\frac{qV}{2k_0T}\right] \quad (6)$$

Simplify (6), according to the theory of semiconductor, substituted (3) and (4) into the original expression of effective optical power, the effective optical power of CCD can be calculated by

$$P=\eta Ach\upsilon\tau_{ph}\beta_{sp}\times\frac{2\sqrt{D_n n_i}\exp\left[\frac{qV}{2k_0T}\right]\times\frac{I_{CCD}}{qV_{act}}}{2\sqrt{D_n n_i}\exp\left[\frac{qV}{2k_0T}\right]+N_A d\sqrt{CN_{t,CCD}}}$$

(7)

CCD converts optical signal to current signal or voltage signal after receiving the optical signal. The CCD's photosensitive surface is irradiated by the incident light, stirring up carriers in its interior [8]. Because of the response speed, the CCD only responds to absorbed light intensity or the average photon number within several cycles, so the carrier's generation rate G is proportional to the incident light energy, $h\upsilon$ is the energy of each photon.

$$G=\frac{\eta P}{h\upsilon}$$

(8)

Because every carrier which is generated by irradiation passing the space charge layer with the average flowing velocity, the instantaneous electric current which all carriers contribute to the detection circuit is

$$\bar{i}=\sqrt{2}\alpha\frac{q\eta P}{h\upsilon}\kappa(\omega) \quad (9)$$

$\bar{i}$ is the average optical current of the detection circuit, G is the generation rate of the receiving detector's carrier, η is quantum efficiency (the probability of one photon excites carrier), α is the modulation depth of the detection circuit, $\kappa(\omega)$ is its transport factor[9,10].

There is a relationship between the luminous intensity and the forward voltage, when the electron diffusion length, electron diffusion coefficient, acceptor concentration, active layer thickness, effective area of the active layer, power of each photon, optical efficiency, speed of light are known, the output power of CCD and the forward voltage is exponential function. Because the effective optical current is the same as input current, the CCD's current is proportional to the light energy. All of these will affect the system's detection performance and reduce the capture rate.

3. Detection performance analysis and output signal calculation method in photoelectric tracking system

According to optical detection principle of the orbital photoelectric tracking system, assuming the spectral radiance of background light is $E_B(\lambda)$, the spectra radiance of background can be expressed by formula(10).

$$E_1=\int_{\lambda_1}^{\lambda_2}E_B(\lambda)d\lambda \quad (10)$$

λ_1 and λ_2 are spectra wavelength which is responded by CCD detector, and according to the effective aperture of the optical lens, the receiving total luminous flux of the photoelectric tracking system is:

$$\Phi=\int_{\lambda_1}^{\lambda_2}\frac{1}{4}\cdot\pi D^2\cdot E_{\mathrm{B}}(\lambda)d\lambda \quad (11)$$

D is the effective aperture diameter of lens. If the light transmittance of the optical lens is τ, the receiving luminous flux on the photosensitive surface of the CCD detecting element is:

$$\Phi=\int_{\lambda_1}^{\lambda_2}\tau\cdot\frac{1}{4}\cdot\pi D^2\cdot E_{\mathrm{B}}(\lambda)d\lambda \quad (12)$$

If the CCD's exposure time is t, the receiving total radiant energy on the photosensitive surface of the CCD detecting element is:

$$Q=\int_{\lambda_1}^{\lambda_2}t\cdot\tau\cdot\frac{1}{4}\cdot\pi D^2\cdot E_{\mathrm{B}}(\lambda)d\lambda \quad (13)$$

According to the principle of CCD optical coupling detection, assume the spectra quantum efficiency of CCD detector is $\eta(\lambda)$, and then the number of spectra's photoproduction electrons on the photosensitive surface is:

$$N(\lambda)=\int_{\lambda_1}^{\lambda_2}t\cdot\tau\cdot\eta(\lambda)\cdot\frac{1}{4}\cdot\pi D^2\cdot\frac{\lambda}{hc}E_{\mathrm{B}}(\lambda)d\lambda \quad (14)$$

For the orbital photoelectric tracking system, if target's imaging cover energy is divided by M pixels of the CCD, the amplitude of the output voltage is:

$$V=\int_{\lambda_1}^{\lambda_2}t\cdot\tau\cdot\eta_t\cdot e\cdot\eta(\lambda)\cdot\frac{1}{4CG}\cdot\pi D^2\cdot\frac{\lambda}{hc}E_{\mathrm{B}}(\lambda)d\lambda \quad (15)$$

In (15), G is the gain of amplifier, C is the equivalent capacitance, η_t is the total charge transfer efficiency, e is the electron charge.

Through relevant parameter of the photoelectric tracking system, the amplitude of output voltage of photoelectric detection CCD element in different illumination can be obtained.

4. Calculation and analysis

According to the target detection ability calculation model and calculation method, we calculate the relationship between limited detectable distance and exposure time of the CCD camera, limited detectable distance and dark current, and so on.

Assuming the average capable wavelength of CCD is 680nm, on the whole ballistic movement, the average pixel M that can be imaged in CCD detector is equal to 6.7, the transmittance of optical lens $\tau_0 = 0.68$, optical lens aperture $D = 125mm$, $N_d = 160e^-$, spectral quantum efficiency of measuring wavelength average by CCD in the average value of photoelectric tracking detection system $\eta = 0.88$. If CCD camera exposure time $t_0 = 0.2s$, background illumination is equal to 3×103cd/m2, the changes occur on CCD camera exposure time, photoelectric detection system SNR threshold and dark current of photoelectric detection system, the corresponding change curve can be obtained.

Figure 2 is the relationship between the limited detectable distance and the threshold of SNR. From Figure 2, the result shows that along with the threshold of SNR's decrease, the limited detectable distance increases, and it's useful for tracking the target, especially in the light conditions when the background environment is strong, here, we use magnitude to indicate limited detectable distance. The larger the SNR is, the greater the detection performance is, and the photoelectric tracking system becomes more stable.

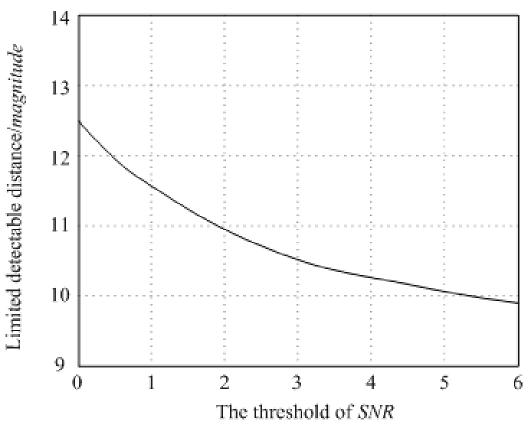

Figure 2. The relationship between detectable distance and the threshold of SNR

Figure 3 is the relationship between the limit of detectable distance and CCD camera exposure time. From Fig.3, the result shows that the longer the exposure time of CCD camera is, the higher the value of the limited detectable distance is. It indicates that the detection performance of the optical system can be improved by choosing feat exposure time in the condition of stable rotating platform.

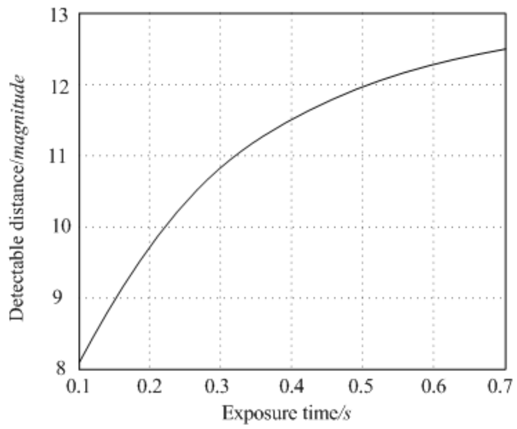

Figure 3. The relationship between detectable distance and exposure time of CCD

Figure 4 is the relationship between the limit of detectable distance and photoelectric detection system of dark current. From Figure 4, the result shows that along with the dark current's decrease, the limited detectable distance increases, and the detection performance also improves. But through analyzing the change in the curve, the influence by the variation of the dark current becomes weak, when dark current changes from $90e^-$ to $130e^-$. Thus, in order to effectively improve the limited detectable distance, we increase the exposure time as far as possible, make the threshold of SNR decrease, and at the same time, we can increase the effective aperture of the optical lens to improve the detection performance.

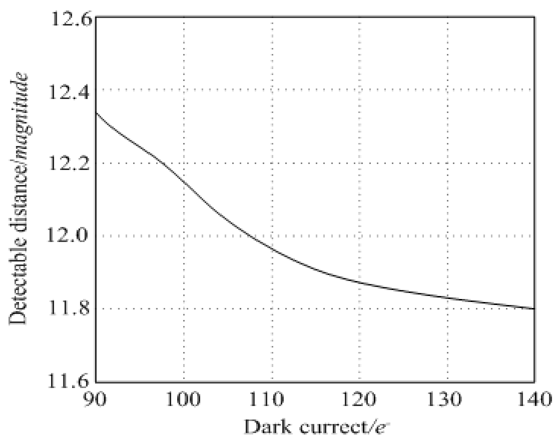

Figure 4. The relationship between detectable distance and dark current

5. Experiment analysis

Based on platform of photoelectric tracking system, we gather some test data. Table 1 and table 2 are the part of data obtained during the unit time Δt, the value Δt of rotating angle control of tracking platform is 0.3s. According to the difference between the theoretical speed and the actual speed of control angle calculation and the difference between the desired angle in theory and the measured angle, we can calculate their error and gain average output signal amplitude.

Table 1. Test data at initial position of tracking path

Desired angle in theory(o)	the measured angle(o)	Average output signal amplitude(mV)	$\Delta\theta$
18.44	19.26	3205	-0.82
19.51	20.08	3317	-0.57
21.73	22.17	3408	-0.44
23.78	24.64	3302	-0.86
24.92	25.28	3526	-0.36
26.67	27.19	3718	-0.52
29.08	29.91	3573	-0.83
31.21	32.47	3682	-1.26
33.45	34.29	3584	-0.84

Table 2. Test data at intermediate position of tracking path

Desired angle in theory(o)	the measured angle(o)	Average output signal amplitude(mV)	$\Delta\theta$
56.92	55.16	3012	1.76
57.88	56.03	3179	1.85
59.04	60.82	3108	-1.78
61.23	62.77	3214	-1.54
62.78	63.85	3077	-1.07
63.97	64.92	3062	-0.95
65.13	67.87	3141	-2.74
67.99	69.61	3055	-1.62
69.47	71.26	2942	-1.79

Through data analysis in table 1, it can be seen that the average value of tracking angle error at initial position is about -0.72 degree, and average output signal amplitude about is 3479mV. According to the space geometry relationship, it can be seen the target offset in the tracking path is about 5.76 m. The resolution of the tracking camera is 2046×1028, its pixel size is $10um$, the focal length of optical lens is with 125mm lens. According to the detection principle of photoelectric tracking system, the amount of deviation of imaging offset in the objective lens is 0.65mm, this value is far less than the image plane of 20mm×10mm. In the range of allowable error, the tracking target can be ensured in the effective field of view, which illustrate the tracking system is stable. In table 2, it can be seen that the average value of tracking angle error at intermediate position is about -0.87 degree, and average output signal amplitude about is 3087mV. From table 1 and table 2, we know that the target distance is far, and the output signal is low, but, the theoretical speed and the actual speed of control angle are basically consistent.

6. Conclusions

According to the principle of target tracking system, we analyze optoelectronic properties of photoelectric detection system and set up the model of optoelectronic properties of target, analyze and deduce the instantaneous electric current of CCD, discuss the detection performance based on characteristics of the target luminance, background luminance and CCD noise; give the output signal calculation method. The results show that the longer the exposure time of CCD camera is, the higher the value of the limited detectable distance is; along with the dark current's decrease, the limited detectable distance increases, and the detection performance also improves; the target distance is far, and the output signal is low, from experiment, the results show the theoretical speed and the actual speed of control angle is basically consistent, and verify the calculation method of target detection ability is correct. The calculation method of target detection ability can applied in laser detection and visible light detection system, which can effectively improve detection performance.

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