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Original research article

Detection distance calculation model of flying target and atmospheric influence analysis

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A R T I C L E I N F O

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In complex environment, target characteristic and atmosphere will affect the performance of the photoelectric track and detection system, it makes the detection sensitivity of photoelectric detection image system will be weaken, to improve its detection ability, this paper researches a new calculation detection distance method and analyze atmosphere influence based on the principle of photoelectric tracking system; analyze the function relationship between surface temperature distribution and flight time, set up the calculation model of target surface radiation energy by dividing target surface into two-dimensional direction multi-cell-grid, and give scientific computing process; derive the calculation function detection distance of flight target and analyze the influence factors on atmosphere to detection distance and detection performance. Through calculation and analysis, the results show the detection distance calculation function can correct describe the real detection performance of photoelectric track and detection system; give the changing curve in different detection distance the photo-electronic sensor gain the radiation energy.

1. Introduction

With the rapid development of infrared technology and infrared detectors, infrared detection equipment has been widely used in military field, especially the exterior ballistics in photoelectric tracking system. Because of its infrared detection technology, photoelectric tracking system is less affected by weather conditions, so it can achieve a full day of work. It is indispensable testing equipment for tracking at night [1].

However, the tracking target in photoelectric tracking system are usually dynamic targets in remote flight, due to far tracking distance, photoelectric tracking system is affected by itself tracking detector, target radiation characteristics and atmosphere [2,3]. When the parameters of photoelectric detector and optical system are determined, the most obvious effect is the radiation of target to tracking. This effect depends on radiation energy of the target radiation reaching photoelectric detector of tracking system. Therefore, infrared radiation characteristic of target restricts the tracking reliability of photoelectric tracking platform. In addition, atmospheric transmittance and detection range can also affect target radiation energy [4]. At present, the distributions of radiation intensity are analyzed and calculated in some research. However, the detection range of remote photoelectric tracking infrared target are relatively less, which are effected by atmosphere, are given less. Based on infrared characteristics of photoelectric tracking space target, this paper researches the calculation model of target infrared radiation in photoelectric tracking system and set up a new calculation detection distance method under the atmospheric influence.

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2. The measurement principles for space target infrared radiation characteristics in photoelectric tracking system

In outside ballistic of photoelectric tracking system, it is composed of photoelectric tracking platforms, data acquisition, optical detection receiver module and computer modules. For tracking optics system, the process of tracking is often affected by the atmosphere, how to get the infrared radiation characteristic parameters of space targets is the essential condition for stable tracking. Therefore, the target radiation of infrared imaging system should be measured. However, during target radiation approaching detection sensors, target radiation is effected by atmospheric attenuation [5]; atmospheric radiation also arrives in photoelectric detecting sensors. The calculation model of target radiation under atmospheric environment can be expressed by Formula (1).

$$Y = \alpha \cdot (\tau_0 L_t + L_e) + Y_0 \tag{1}$$

In (1), Y is the output value of target infrared imaging system, α is radiance response of infrared imaging system ($1/W \cdot m^{-2} \cdot sr^{-1}$), L_t is target radiation brightness; τ_0 is atmospheric transmittance. L_e is path radiation between target and photoelectric tracking platform. Y_0 is biasing caused by infrared imaging tracking system itself thermal radiation and dark current of infrared detectors by environmental background radiation, Y and Y_0 are dimensionless parameters, they are usually indicated by gray-scale value.

According to Formula (1), the radiance of target can be inverted to Formula (2).

$$L_t = [(Y_t - Y)/\alpha - L_e]/\tau_0 \tag{2}$$

From (2), in photoelectric tracking system, in order to obtain radiation characteristics of target, when satisfy a certain radiance, radiation intensity is associated with radiation responsiveness and atmospheric transmittance. Therefore, in order to enhance the detection performance of photoelectric tracking system, infrared radiation detection performance of photoelectric tracking system influenced by atmosphere should be studied.

3. Target radiation calculation model in photoelectric tracking system

3.1. Function relationship between surface temperature distribution and flight time

According to simplified tracking trajectory model, the function relationship between surface temperature distribution and time can be obtained by Formula (3).

$$cm\frac{\partial T}{\partial t} = \begin{cases} -\varepsilon\sigma T^4 - \dfrac{0.664\pi d(Re(t))^{0.5}Pr^{1/3}\alpha_0}{x}T \\ +\dfrac{0.664\pi d(Re(t))^{0.5}Pr^{1/3}\alpha_0}{x}T_w(t) \\ \quad +\varepsilon\sigma T_e^4 + Q_e, \quad R_e < 10^5 \\ -\varepsilon\sigma T^4 - \dfrac{0.036\pi d(Re(t))^{0.5}Pr^{1/3}\alpha_0}{x}T \\ +\dfrac{0.036\pi d(Re(t))^{0.5}Pr^{1/3}\alpha_0}{x}T_w(t) \\ \quad +\varepsilon\sigma T_e^4 + Q_e, \quad 10^5 \le R_e < 10^7 \end{cases} \tag{3}$$

In (3), c is ballistic coefficient, m is target quality, T is target surface temperature, ε is launching rate of target surface material, σ is Boltzmann constant, x is length of the target attribute, $Re(t)$ is Reynolds number at t moment, p_r is Prandtl number, α_0 is thermal coefficient of liquid, d is target cross section diameter, T_w is temperature of insulated wall, T_e is environment temperature, Q_e is environmental radiation heat.

According to Formula (3), we can calculate the changing rule of surface temperature distribution of flight target and time. The surface spectral radiant exitance of target is can be gain by Formula (4).

$$M_\lambda = \varepsilon \cdot g \cdot \frac{c_1}{\lambda^5(e^{c_2/\lambda T} - 1)} \tag{4}$$

In (4), λ is the radiation wavelength (μm), c_1 and c_2 are radiation constant, $c_1 = 3.74 \times 16^{-16}(Wm^2)$, $c_2 = 1.43879 \times 10^{-2}(mK)$, g is radiation emissivity of target material [6].

Combine Formulas (2) and (4), we can gain and calculate the target radiation brightness under certain atmospheric effects.

3.2. Target surface radiation calculation method in optical field of view

Heat radiation of target of photoelectric tracking system in optical field of view mainly depends on around environment, as well as heat exchange and heat balance in internal target, heat radiation factors that deciding target are a lot, such as,