A calculation method of operation range of infrared point target in photoelectric detection system based on considering the target diffuse spot

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The detection distance of infrared photoelectric detection system is determined by photoelectric detector characteristics, target and background radiation, target imaging diffuse spot size and other factors. But the traditional calculation function of detection distance of system that doesn't consider the target imaging diffuse spot on the photoelectric detector, it makes the calculated target distance always longer than the actual target distance. To solve this problem, based on the basic principle of infrared photoelectric detection system and the existing problems in traditional calculation function, this paper proposes a new calculation model of detection distance considering target diffuse spot of system, which derives point target diffuse spot calculation function and total radiation energy function, and presents the new detection distance function of system. This detection distance function ignores the influence of background environment, by combining the system modulation contrast parameters and considering optical lens emissivity, background emissivity and target emissivity in actual testing environments, a more precise detection distance function is established. The experimental verification shows that the detection distance calculation model considering diffuse spot and system modulation contrast can calculates more accurate target distance than traditional model, which proves the new model is more effective and scientific.

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Keywords: Infrared photoelectric detection system, Detection distance, Diffuse spot, Target and background radiation, Modulation contrast

1. Introduction

Infrared photoelectric detection system is widely used in night detection, target tracking, weapon equipment detection and other aspects. The detection system is mainly composed of optical lens, infrared photoelectric detector, detection conversion processing module and image conversion processing module, among which the most important part is the infrared photoelectric detector [1]. Infrared detection distance is one of the important indexes to measure the performance of infrared photoelectric detector, and it is also a key index to affect its battlefield practicability. The size of detection distance directly restricts the application of infrared photoelectric detection system, especially when it is applied to video tracking, small target detection at night, long-range missile flight state monitoring and so on. At present, the factors that affect the detection distance of infrared photoelectric detection system include optical lens, specific detection rate of infrared photoelectric detector, photosensitive surface area of detector, system bandwidth, signal-to-noise ratio, detection background environment, radiation intensity of the detected target and so on [2-3]. In the actual detection environment, the parameters such as ambient temperature, ambient spectral illumination and the target's own radiation energy are constantly changing, which makes the detection distance of infrared photoelectric detection system change greatly. However, in the traditional detection distance calculation model, only the target radiation energy is considered, so the calculated detection distance is often greater than the actual target distance [4]. There are two obvious limitations in this model. On the one hand, traditional detection distance function does not consider the point target diffuse spot problem. For the point target, the imaging point on the detector is diffuse, and the dispersion angle is much larger than the projection angle of the point target. If the diffuse spot problem of point target is not considered, it will obviously lead to inaccurate calculation results. On the other hand, traditional detection model ignores the influence of detection environment. In fact, changing ambient temperature, spectral illumination and optical lens resolution all affect the detection distance.

In order to improve the detection capability of the infrared photoelectric detection system, there are many related scientific research were published. For example, to solve the problem of inaccurate calculation of traditional model in complex background environment, a detecting different radiation brightness regions probabilistic calculation method was proposed based on the rose-scanning system [5]. And then, the distance model of rose-scanning infrared detection system was derived, which the probability model of the detection distance of the rose scanning infrared detection system under complex background was established. Another researcher analyzed the main affect actors that make point target form diffuse spot on detector's target surface [6]. The pixel number of point-target diffuse spot was calculated and the improved detection distance function considering the diffuse spot was derived. There is also a research that using a NETD distance model by iterative calculation to establish the infrared photoelectric detection distance model [7]. Starting from the thermal radiation of the infrared detection system itself and the classical detection distance theory, the calculation model of the detection distance of the infrared detection system including system noise is derived, and an analysis method for distributed detection distance is proposed [8]. Taking unmanned aerial vehicle (UAV) clusters as the research object, the detection capability of aerial and sky infrared detection systems on UAV clusters is analyzed; A noise equivalent flux density point target detection distance model based on diffusion coefficient is established; By using different modeling methods and comparing different dispersion coefficients, the variation of detection distance with the signal-to-noise ratio and velocity of the target is analyzed to verify the effectiveness of the proposed detection distance model [9]. Regarding infrared target detection methods, Reference [10] proposes a low altitude sea surface infrared target detection method based on unsupervised domain adaptation, which utilizes YOLOv5s unsupervised domain adaptation to target detection networks, effectively reducing the impact of non-uniformity of different infrared detectors in low altitude sea background on lightweight detection networks, and improving the network’s generalization capability in different infrared detector applications. When the airborne infrared photoelectric detection system detects targets in complex scenes using downward looking, the ground false alarm interference source is consistent with the spatial distribution of weak and small targets, and traditional algorithms can lead to a large number of false alarms; Reference [11] proposed a multi-dimensional feature association detection algorithm based on moving target features, a frame skipping mechanism is introduced based on the relative speed to height ratio between the carrier aircraft and target, and candidate targets are extracted using a moving target model, the method combines multi-dimensional feature association to determine the target for low false alarm infrared target detection. Aiming at the problem that infrared target detection in ground scenes is vulnerable to complex background interference, low detection accuracy, and prone to false detection and missed detection, taking vehicle infrared characteristics as the research object, Reference [12] proposed infrared target detection method based on global awareness mechanism, constructed Infrared-YOLO infrared target detection method based on global awareness mechanism, improved the detection accuracy of infrared targets in ground background, and realized real-time detection.

In this paper, based on the principle of infrared photoelectric detection system and traditional detection distance function, we consider the effect of target diffuse spot and detection background environment, and establish a new detection distance model and method of infrared photoelectric detection system which considers the target imaging diffuse spot and system modulation contrast. This paper aims to improve traditional detection distance function to establish the new model that can calculate more exact target distance, and the main contributions of this work are as follows:

(1) Taking into account atmospheric jitter and image point dispersion caused by optical imaging, a calculation model for the spot size of point target dispersion imaging on a photoelectric detector is established.

(2) The correlation model between the target radiant power induced by the infrared photoelectric detector and its output voltage is established, and the detection distance calculation model of the infrared detection system under the influence of background is deduced.

(3) By introducing the modulation contrast parameter, combined with the inherent parameter information of the detection system itself, a new detection distance calculation model for the infrared photoelectric detection system is constructed. The scientificity of the detection distance calculation model has been verified through calculation analysis and experimental results.

The structure of this paper is organized as follows. Section 2 states the basic principle of infrared photoelectric detection system and target diffuse spot calculation function analysis. Section 3 sets up the calculation model of detection distance considering the target diffuse spot. Section 4 states the detection distance calculation method considering the modulation contrast. Section 5 gives the experimental analysis. Finally, the conclusions are drawn in Section 6.

2. Basic principle of infrared photoelectric detection system and target diffuse spot calculation function analysis

2.1. Basic principle of infrared photoelectric detection system

The infrared photoelectric detection system is mainly composed by optical lens, infrared photoelectric detector and detection and image conversion processing module [13]. The basic principle of the system is shown in Fig. 1. In Fig. 1, Ω is the effective field of view of the optical system, R is the distance between the target and the optical imaging system, which is called the detection distance of the system.

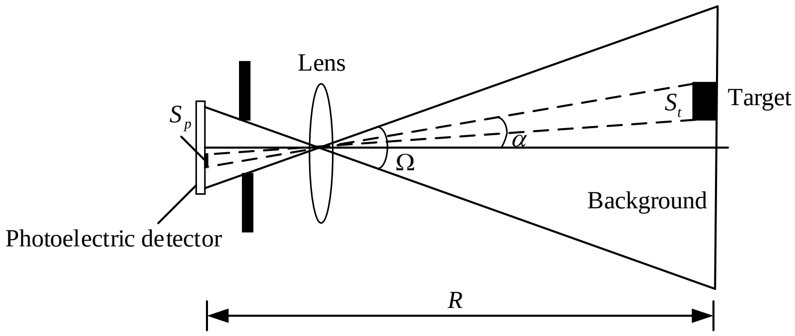


Fig. 1. Basic principle of infrared photoelectric detection system

The traditional detection distance function is as follows [14]:

$$R = \sqrt{\frac{\pi \tau_a \tau_0 S_0 I_t N_A D^*}{2n_1 (\alpha \Delta f)^{1/2} \cdot SNR}} \tag{1}$$

where τ_a is atmospheric transmittance; τ_0 is the transmittance of optical system; S_0 is the effective area of the optical system; I_t is the target infrared radiation energy; N_A is the numerical aperture of the optical system; D^* is the detection rate of infrared photoelectric detector; n_1 is the number of pixels of the target imaging on the photosensitive surface of photoelectric detector; α is the field of view angle corresponding to a single pixel of the infrared photoelectric detector; Δf is the equivalent noise bandwidth; and SNR is the signal-to-noise ratio; α is obtained by Formula (2):

$$\alpha = \frac{S_d}{f^2} \tag{2}$$

where S_d is the single pixel area of the infrared photoelectric detector; and f is the focal length of optical lens.

It can be seen from the Formula (1) that the detection distance of the infrared photoelectric detection system is related to the transmittance, effective area and numerical aperture of the optical system, the specific detection rate and number of pixels of the photoelectric detector, etc. Among them, the imaging size of the target on the photoelectric detector is an important factor affecting the detection distance of the system. For the point target, due to the diffraction effect of the optical system, the target energy received by the system at the entry pupil is diffused, which makes target imaging of the photoelectric detector create diffuse spot. However, the traditional detection distance function does not take into account the influence of the diffuse spot and the background radiation. This leads to a large error when detecting the target. In order to more scientifically characterize the detection distance of infrared photoelectric detection system, the model takes into account the area of the diffuse spot on the photoelectric detector and the influence of background radiation.

2.2. The parameters calculation method of target diffuse spot

According to the working principle of the infrared photoelectric detection system, when the target is detected in the effective field of view of the system, the target will form a certain size image on the photoelectric detector. If the number of pixels on the photoelectric detector is greater than one unit pixel, it is called surface target. If the number of pixels on the infrared photoelectric detector is less than one unit pixel, it is called point target [15-16]. Assume the solid angle of the target relative to the photoelectric detector is Ω_{tr}, according to the point target definition, the relationship between Ω_{tr} and α can be given by Formula (3).

$$\Omega_{tr} = \frac{S_t}{R^2} < \alpha = \frac{S_d}{f^2} \tag{3}$$

where S_t is the target effective cross-sectional area in the effective field of view of the system.

When the system detects a target, the detection distance is far, and the solid angle of the target relative to the detector at the distance *R* is less than the field of view of a single pixel of the detector. According to the characterization function, the target detected by the system can be determined as a point target, and the distance parameter in this function is called the critical distance [17]. Based on Formula (3), if the detection distance of the system and the area of the minimum imaging quantity of the target in the infrared photoelectric detector are known, the effective field of view of the optical imaging system can be determined.

If S_p represents the target imaging area on the photosensitive surface of infrared photoelectric detector; the relationship between S_t and S_p is obtained as follows:

$$S_p = S_t f^2 / R^2 \tag{4}$$

The critical relationship between point target and surface target can be characterized by the critical distance R_0, which is calculated by Formula (5):

$$R_0 = \sqrt{S_t f^2 / S_d} \tag{5}$$

When the detection distance R is greater than the critical distance R_0, that is $R \geq R_0$, the image of the target is a point target.

In the traditional detection distance model, the calculation function of the number of theoretical imaging pixels occupied by the spot formed by the photoelectric detector for target imaging is as follows:

$$n_1 = \frac{\Omega_I}{\alpha} = \frac{\pi(\beta_T / 2)^2}{S_d / f^2} \tag{6}$$

where Ω_I is the solid angle corresponding to the target image; β_T is the view angle corresponding to the target. From the Formula (6), it can be found that the traditional calculation function does not take into account the influence of background environment and target diffuse spot when it uses the number of pixels [18]. But for the point target, the theoretical imaging pixels is small, which is clearly needs to be improved.

If λ is the average wavelength detected by the photoelectric detector; r_0 is the atmospheric coherence length; and D is the aperture of the optical system, the field angle corresponding to the dispersion imaging of the target codetermination by the actual detection target and the background, is given by Formula (7).

$$\beta = \sqrt{\beta_T{}^2 + (\lambda / r_0)^2 + (\lambda / D)^2} \tag{7}$$

According to the Formula (7), the pixel number of photoelectric detector calculation function that considers the environmental factors and diffuse spot is established by Formula (8).

$$n = \sqrt{\frac{\pi(\phi / R)^2 + \pi(\lambda / r_0)^2 + \pi(\lambda / D)^2}{4S_d / f^2}} \tag{8}$$

where ϕ is the diameter of the target. As can be seen from Formula (8), the imaging size of the point target under the action of dispersion is mainly determined by the point dispersion caused by the last two atmospheric jitter terms and the point dispersion caused by the optical system. This also reflects that the detection capability of the infrared photoelectric detection system is not only determined by the size of the target itself, but also related to the environmental factors. Therefore, it is not perfect for the traditional detection distance model of the system to consider only the size of the target itself.

3. The calculation model of detection distance considering the target diffuse spot

In the traditional detection distance model of the system, it mainly considers the target radiation energy and the number of theoretical imaging pixels [19]. However, for a point target, the target imaging on the photosensitive surface of the photoelectric detector is relatively small, so detector will also receive relatively large background radiation energy in addition to the target radiation energy. Moreover, the point target diffuse spot will also cause the pixel number of the target image increase.

The total radiation energy of photoelectric detector includes target radiation energy and background radiation energy. Assume I_t and I_b are the target radiation energy and background radiation energy, respectively. According to Planck's theory, the total radiation energy function of photoelectric detector can be derived.

$$I = I_t + I_b = \frac{\varepsilon_t S_t}{\pi} \int_{\lambda}^{\lambda_2} \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T_t} - 1} d\lambda + \frac{\varepsilon_b(\Omega R^2 - S_t)}{\pi} \int_{\lambda}^{\lambda_2} \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T_b} - 1} d\lambda \tag{9}$$

where ε_t and ε_b are the emissivity of target and background, respectively; T_t and T_b are the temperature of target and background, respectively; c_1 and c_2 are radiation constants [20]. It is not enough to only establish the total radiation energy calculation function, but also need to consider the influence of signal-to-noise ratio on the detection distance calculation model [21]. According to Formula (9), the target radiation power and background radiation power received on the photosensitive surface of the photoelectric detector are obtained as follows:

$$P_t = \frac{I_t \cdot \tau_a}{R^2} S_0 \tau_0 = \frac{\varepsilon_t S_t}{\pi} \frac{S_0 \tau_a \tau_0}{R^2} \int_{\lambda}^{\lambda_2} \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T} - 1} d\lambda \tag{10}$$

$$P_b = \frac{I_b \cdot \tau_a}{R^2} S_0 \tau_0 = \frac{\varepsilon_b(\Omega R^2 - S_t)}{\pi} \frac{S_0 \tau_a \tau_0}{R^2} \int_{\lambda}^{\lambda_2} \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T} - 1} d\lambda \tag{11}$$

where P_t and P_b are target radiation power and background radiation power, respectively. Assuming the spectral response rate of the photoelectric detector is σ_0

[22]; output target signal voltage V_s and background signal voltage V_n of the photoelectric detector are shown in Formulas (12) and (13).

$$V_n = \sigma_0 S_0 \tau_0 \frac{I_b \cdot \tau_a}{R^2} \tag{12}$$

$$V_s = \sigma_0 S_0 \tau_0 \frac{I_t \cdot \tau_a}{R^2} \tag{13}$$

The signal-to-noise ratio of the system can be expressed as follows:

$$SNR = \frac{V_s}{V_n} = \frac{I_t}{I_b} \tag{14}$$

Combining the target diffuse spot calculation function and total radiation energy calculation function, considering diffuse spot, the detection distance model of infrared photoelectric detection system is obtained by Formula (15).

$$R = \sqrt{I \cdot \tau_a \cdot \frac{\tau_0 S_0 D^*}{n S_d^{1/2}} \frac{1}{SNR \cdot \Delta f^{1/2}}} \tag{15}$$

4. The detection distance calculation method considering the modulation contrast

Infrared photoelectric detection system is sensitive to environmental changes. In order to further optimize the detection distance model, the modulation contrast is introduced to establish the new detection distance model of infrared photoelectric detection system under different detection environments.

For the point target, the target diffuse spot area S_m can be calculated by a single pixel area on the photoelectric detector and the number of pixels of the target image on the photoelectric detector's surface, which is shown as follows:

$$S_m = n \cdot S_d \tag{16}$$

Then, the target irradiance obtained on the photoelectric detector can be expressed by Formula (17).

$$L_t = \frac{\tau_0 \tau_a \varepsilon_t}{4} \frac{S_t}{S_m} \left| \frac{D}{R} \right|^2 \int_{\lambda}^{\lambda_2} \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T_t} - 1} d\lambda \tag{17}$$

The irradiance of the optical lens radiated on the photoelectric detector is:

$$L_0 = \frac{\varepsilon_0}{4} \left| \frac{D}{f} \right|^2 \int_{\lambda}^{\lambda_2} \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T_0} - 1} d\lambda \tag{18}$$

where ε_0 is the emissivity of the optical lens; and T_0 is the temperature of the optical lens [23-24].

According to Formulas (17) and (18), the modulation contrast of the detection system is:

$$C_M = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}} = \frac{L_t}{L_t + 2(L_b + L_0)} \tag{19}$$

where L_b is the irradiance generated by background radiation on the photoelectric detector.

According to Formulas (15) and (19), the detection distance calculation function considering the modulation contrast can be expressed as follows:

$$R = \sqrt{I \cdot \tau_a \cdot \frac{\tau_0 S_0 D^*}{n S_d^{1/2}} \frac{1}{SNR \cdot \Delta f^{1/2}} \left| \frac{1 - C_M}{C_M} \right|} \tag{20}$$

The diffusion coefficient is used to characterize the diffusion phenomenon generated by target imaging. The radiation flux of point targets forming diffusion spots is the same as the radiation flux generated at the pupil of the optical system, except that the radiation flux is dispersed in the diffusion pixels. Due to the fact that the actual number of pixels imaged by a point target is smaller than that imaged under diffusion, the detection distance of the point target should be determined by the number of pixels imaged by the diffusion spot of the target. Therefore, it is necessary to establish a calculation function for the number of pixels imaged by the point target on the photosensitive surface of the photoelectric detector. At the same time, the detection capability of infrared photoelectric detection systems is not only related to the signal-to-noise ratio of the system, but also to the contrast between the target and the background. Introducing modulation contrast parameter in the detection distance calculation model can more accurately evaluate the detection distance of the detection system.

5. Experimental analysis

In order to verify whether the improved detection distance model of infrared photoelectric detection system can effectively improve the detection accuracy, many experiments are carried out in this section.

In the experiment, the target and detection background parameters are as follows: the detected target temperature is 550 k, the effective diameter of the target is 0.45 m, the length of the target is 4.72 m, the surface emissivity of the target is 0.65, the detection elevation angle is 45°, the atmospheric disturbance is better than 1″, and the average atmospheric background radiance under the condition of marine aerosol is $25.14\mathrm{W}/\mathrm{m}^2\cdot\mathrm{sr}$. When the camera is in the 3.4-5.3 μm response band, lowtran7 software can calculate the average atmospheric transmittance at different elevation angles, and the calculated results are shown in Fig. 2, and the main parameters of the infrared photoelectric detection system are given in Table 1.

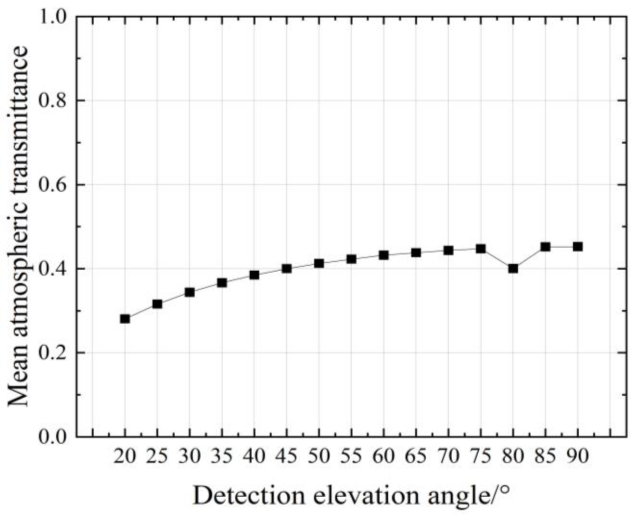


Fig. 2. Average atmospheric transmittance at different elevations

Table 1. Main parameters of infrared photoelectric detection system

Parameter name	Parameter value
Working wavelength	3.4-5.3 μm
Transmittance of optical system	0.78
Optical system aperture	300 mm
Focal length	450 mm
Specific detection rate	3×10^{10} cm·Hz$^{1/2}$/W
Detector resolution	640×512
Pixel size	15 μm×15 μm
Noise equivalent bandwidth	500 Hz

According to the above parameters and experimental conditions, the detection distance function of this paper considering the point target diffuse spot is compared with the traditional detection distance function of the system. The traditional detection distance function of the system does not consider the influence of diffuse spot and background radiation. According to the parameters in Table 1 and Fig. 2, Fig. 3 shows the relationship between target pixel number and detection distance of traditional detection distance function.

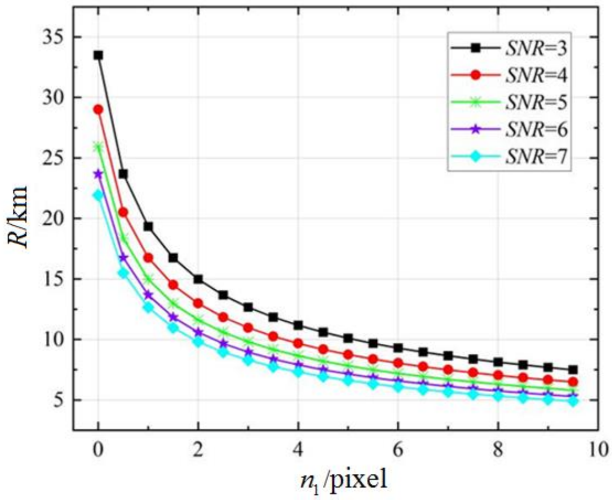


Fig. 3. The relationship between target pixel number and detection distance of traditional detection distance function (color online)

According to Formula (15), the relationship between target pixel number and detection distance considering the target diffuse spot is shown in Fig. 4. For the same target actual distance, the values of n and n_1 are different, so there is the correspondence relationship of n and n_1 at the same target and different detection distances, and which is shown in the Table 2.

Table 2. The correspondence relationship of n and n_1 at the same target and different detection distances

n	n_1
2	11.4
4	13.8
6	16.1
8	18.3
10	20.7

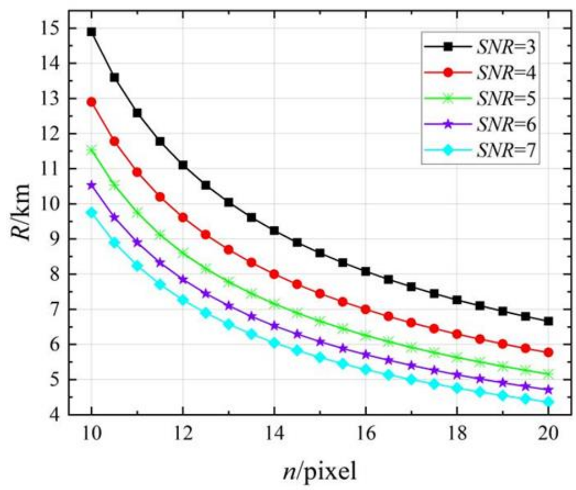
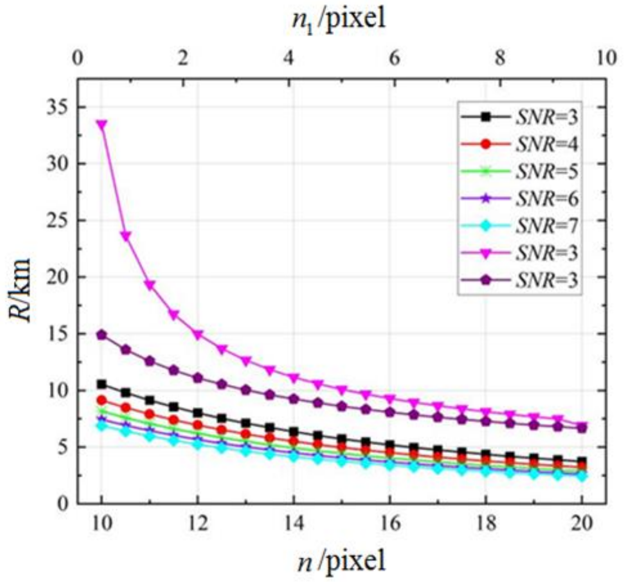


Fig. 4. The relationship between target pixel number and detection distance considering the target diffuse spot

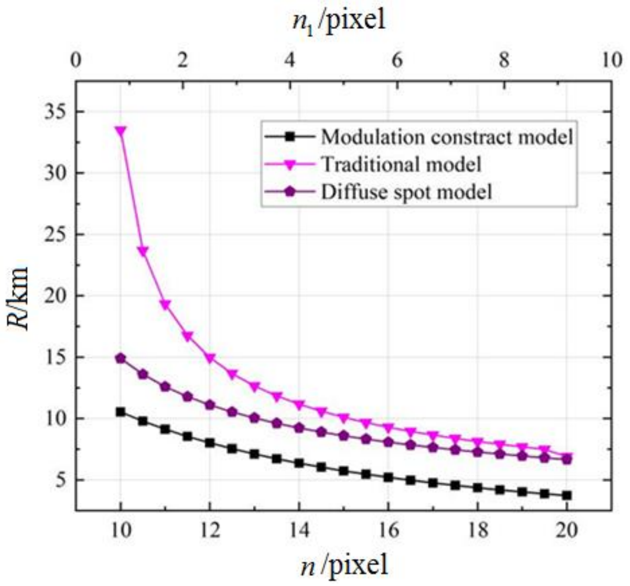
(color online)

For Figs. 3 and 4, the detection distance decreases with the increase of pixel number. This conforms to the basic law that the farther away the detection target, the smaller the target imaging on the photoelectric detector. The smaller the signal-to-noise ratio, the longer the detection distance of the system. Comparing Figs. 3 and 4, under the same detection distance and signal-to-noise ratio, the detection distance function considering diffuse spot is significantly smaller than that the traditional detection distance model.

According to Formula (20), considering target imaging diffuse spot and modulation contrast, the relationship between target pixel number and detection distance is calculated by Fig. 5.



(a) The relationship between detection distance and target pixel number under different signal-to-noise ratios and detection capability calculation model conditions



(b) The relationship between detection distance and target pixel number of three detection capability calculation models under the same signal-to-noise ratio

Fig. 5. The relationship between target pixel number and detection distance (color online)

In Fig. 5(a), the square, circular, star, pentagonal star and diamond curves in the figure represent the calculation results of the detection range model considering the modulation contrast of the system under different signal-to-noise ratios. When the signal-to-noise ratio is 3, the triangular curve represents the calculation result of the traditional detection range model and the pentagon curve represents the calculation result of the detection range model considering the diffuse light spot. To provide a clearer explanation of the differences in calculation models for different detection capabilities, Fig. 5(b) is the relationship between detection distance and target pixel number of three detection capability calculation models under the same signal-to-noise ratio, these detection capability calculation model are traditional detection distance model, the detection distance model considering the diffuse light spot and the detection distance model considering the modulation contrast of the system. According to Formulas (1), (15), and (20), the relationship between signal-to-noise ratio and detection distance is calculated and analyzed, and the detection distance is inversely proportional to the signal-to-noise ratio. As the signal-to-noise ratio increases, the detection distance decreases. The change curve in Fig. 5(a) also follows this pattern. From Fig. 5(b), it can be seen that the detection distance established in this paper has the smallest change with the increase of the number of target imaging pixels, and is less susceptible to the influence of external environment and dispersion phenomena compared to the other two detection capability models.

Compared with Figs. 3-5, under the same detection distance and signal-to-noise ratio, the calculation result of the detection distance model considering the target diffuse spot and system modulation contrast is significantly smaller than that the detection distance model considering only the target diffuse spot and the traditional detection distance model. In the actual detection process, the target diffuse spot and the environment will affect the detection effect, the test result has large error using the traditional detection distance function, and the detection distance is much longer than the actual distance. The proposed detection distance model considering target diffuse spot and modulation contrast can effectively reduce the error.

For the detection distance model of infrared photoelectric detection system, the radiation energy is also an important variable affecting the detection accuracy. For the traditional detection distance model, the radiation energy only considers the detected target, ignoring the influence of environment and diffuse spot. The established detection distance model considering target diffuse spot and modulation contrast is analyzed by the relationship among detection distance, target pixel number and radiation energy. The results are shown in Figs. 6-8.

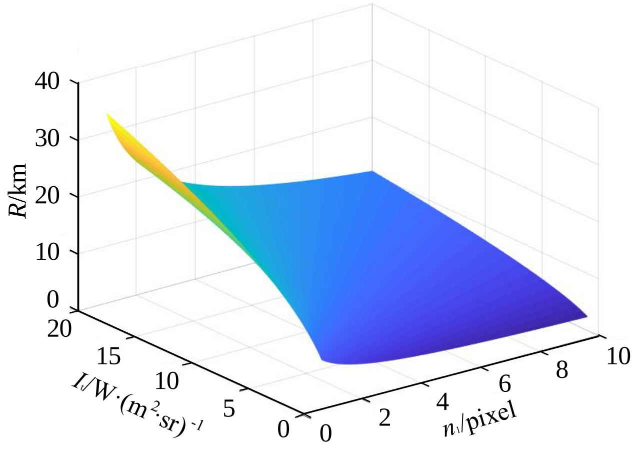


Fig. 6. The relationship among detection distance, target pixel number and radiation energy in traditional model (color online)

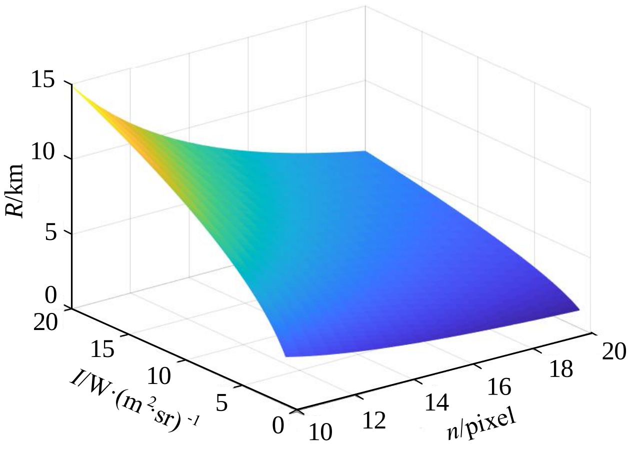


Fig. 7. The relationship among detection distance, target pixel number and radiation energy in dispersive spot model (color online)

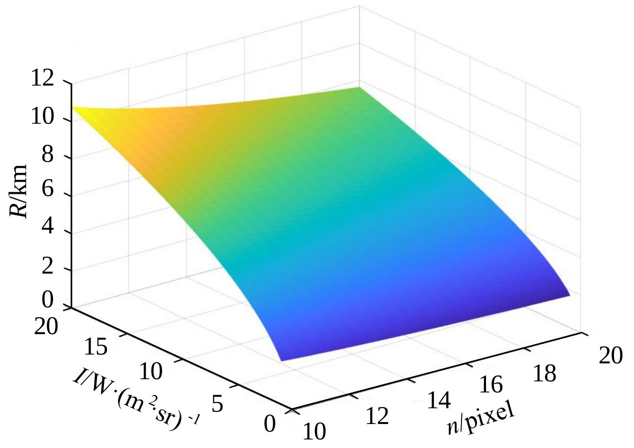


Fig. 8. The relationship between detection distances, target pixel number and radiation energy in modulation contrast model (color online)

From Figs. 6-8, it is obvious that the stronger the radiation energy, the farther the detection distance. However, compared with the results of traditional detection distance function, the detection distance function considering the diffuse spot, and the detection distance function considering target diffuse spot and modulation contrast, the detection distance considering target diffuse spot and modulation contrast is significantly reduced, which accords with the actual detection law, indicating that the new model is more scientific.

In order to further verify that the detection distance function considering target diffuse spot and modulation contrast is closer to the actual target distance, we use the new model and the traditional model to test the detection distance of the blackbody target by different apertures and different focal lengths of optical system. The optical aperture and focal length of the system in the control group are 450 mm and 350 mm, respectively. Figs. 9 and 10 show the two groups comparative results of infrared photoelectric detection systems with different optical apertures and focal lengths, respectively.

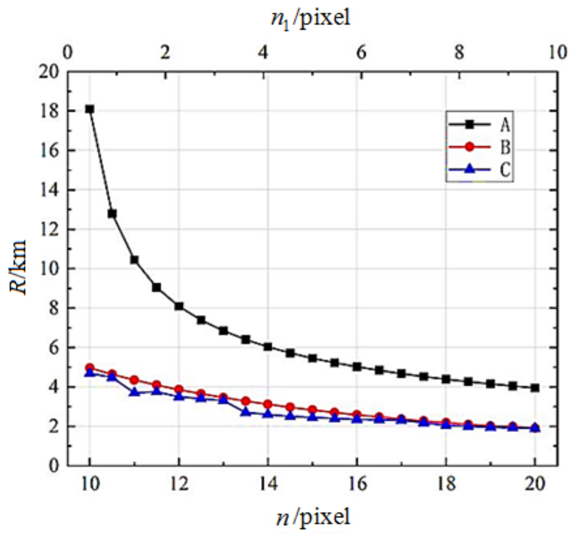


Fig. 9. The detection distance results at the optical aperture of 450 mm and focal length of 350 mm (color online)

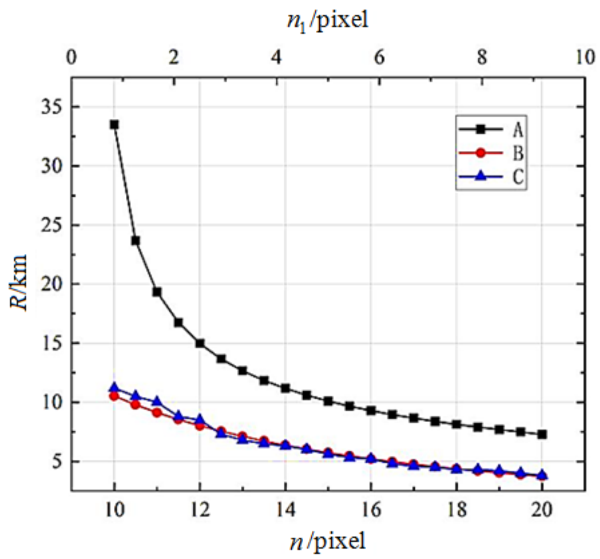


Fig. 10. The detection distance results at the optical aperture of 160 mm and focal length of 200 mm (color online)

In Figs. 9 and 10, the curve A represents the test result of traditional detection distance function, and the curve B represents the test result of detection distance function considering target diffuse spot and modulation contrast and the curve C is the target actually distance. When optical apertures and focal lengths are different, the result error between curves A and B is also small. This fully proves that the detection distance model considering the diffuse spot and the system modulation contrast is more scientific and accurate.

The target detection test of the infrared photoelectric detection system is carried out, and using detection distance model considering the diffuse spot and the modulation contrast, the test result is shown in Fig. 11.

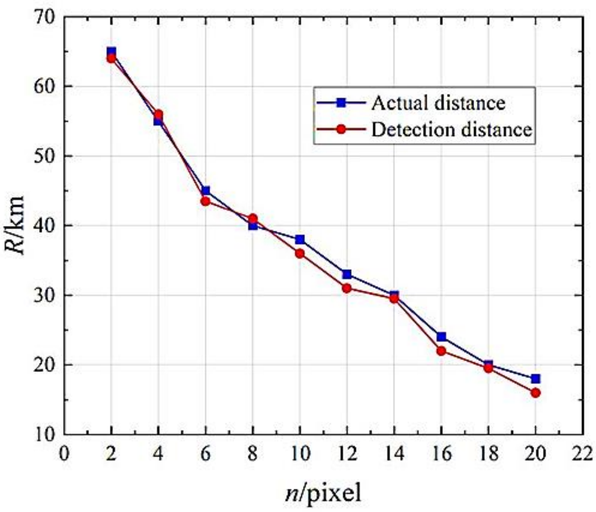


Fig. 11. Target detection test results (color online)

The test results show that the calculated detection distance is basically consistent with the actual distance, and the detection model considering the diffuse spot and system modulation contrast has better detection accuracy.

6. Conclusions

In order to solve the problem that the detection distance calculated by the traditional detection distance calculation model is always greater than the target actual distance, this paper establishes a detection distance calculation model considering the influence of the target dispersion facula and the environment. The calculation functions of dispersion facula, total radiation energy and modulation contrast are established. A new detection distance model of infrared photoelectric detection system is formed. And the established detection distance model is verified by experiments. The experimental results show that under the same conditions, considering the dispersion facula and modulation contrast, the calculated detection distance is closer, which is consistent with the actual distance. The detection distance model proposed in this paper provides a more scientific theoretical and engineering application calculation method for the detection test of blackbody targets in different seasons.

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