Air-Ground Rotary Scanning Imaging System for Ground Vehicles Based on Passive Infrared Detection

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Abstract. General target detection system is based on active detection method, which is usually of poor concealment and bulky. In order to improve the concealment and dexterity of airborne detection, an airborne infrared scanning imaging system for ground vehicles based on passive infrared detection is proposed. Under the condition of guaranteeing the minimum effective detection interval, a rotary scanning dynamic detection model is established based on the principle of single-point passive infrared detection, and the relationships between the detection distance, the rotating angular velocity, the scanning angle, the relative motion velocity and the size of detection area are obtained. According to the expression of infrared characteristic of ground vehicles, the relationship between the response voltage of radiation signal and the relationships among the detection distance is obtained. Based on the projection distribution of the infrared feature area received by the infrared detector, the signal response expression including the size information of the target is obtained at a certain rotating angular velocity. Finally, through simulation and experiment, the system can effectively acquire the signal intensity and signal response width information in the infrared feature area of ground vehicles between the detection distance of 5.4 m and 33.4 m, which verifies the effectiveness of the system.

1. Introduction
Passive infrared detection are useful for many applications in both civil and military areas [1]. Most traditional approaches adopt infrared camera, millimeter wave radar and other detection technology to detect and identify targets. It is widely used in military target recognition [2], aircraft target search [3-4], deep space target detection [5], etc. It has incomparable advantages in the field of anti-terrorism equipment requiring a large number of low-cost detection devices [6-7]. On air-ground infrared scanning imaging platform, the detection of the armored vehicle is uncertain. The infrared photoelectric detection system with rotating scanning in the air receives the radiation energy of the vehicle in the infrared characteristic region and the radiation energy of the vehicle scattering in complex environment. Therefore, the combined action of multiple factors makes the contribution of the vehicle to the energy of the airborne infrared scanning imaging system present a random state. Sharma [8] proposed a new threshold of background subtraction based on linear discriminant ratio (LDR) in the detection of moving human body under the condition of in-depth study of background dynamic change and illumination.
change. Chengyi Xu [9] proposed a new method to adjust the infrared radiation characteristics of the target itself inspired by cephalopod skin. Hanlin Qin [10] proposed a template matched filtering target detection method to improve the detection probability of dim and small targets. Chen Zhong [11] proposed a new spatio-temporal detection method based on two-dimensional empirical mode decomposition and time-domain difference to solve the problem that small moving infrared targets are difficult to detect due to low signal-to-noise ratio and large fluctuation of background. Chengming Sun [12] proposed an accurate modeling method for infrared radiation characteristics of space targets according to the law of light radiation and scattering. Peipei Yan [13] proposed a method for calculating the illumination of the reflected light from the surface of the space target. These researches are based on the infrared radiation characteristics of the target in the static state of the detection system. The model does not consider the influence of the movement state of the detection system and the change of its attitude on the infrared radiation signal characteristics. In the aspect of detection and recognition model and spectral analysis of armored vehicles under unknown motion state, there exists a mechanism of passive detection and recognition from air to ground and infrared radiation analysis under this model has not been studied in depth. The existing detection model and infrared radiation theory are also difficult to quantitatively and qualitatively give the calculation model of passive scanning detection of armored vehicles and infrared radiation analysis of targets. The infrared radiation characteristics expression of ground armored targets with uncertain altitude, uncertain detection distance and uncertain scanning angle for the airborne rotary infrared scanning imaging detection system is establish.

2. Air-ground rotary infrared scanning imaging model for ground vehicles

The principle of the rotary infrared scanning detection system is shown in Fig. 1. The ground vehicle is taken as the reference coordinate system, the forward direction of the ground vehicle is X-axis, and the moving speed is \( v_x \). The unmanned aerial vehicle rotary infrared scanning detection platform, it is detection distance of \( L \), infrared detector field center axis and the angle between the ground plumb axis \( \theta \), scanning angular velocity is \( \omega \), the unmanned aerial vehicle platform moves in the negative direction of the X-axis and the velocity is \( v_r \). The rotary infrared scanning detector receives the infrared radiation characteristics of the reflected environment from the body of the ground vehicle or the surface of the vehicle, which is \( S_1 \), \( S_2 \) and \( S_3 \).

Fig. 1 Rotary infrared scanning detection system for ground vehicles

As shown in Fig. 1, the rotary infrared scanning imaging detection system consists of a passive infrared detection system, an unmanned aerial vehicle, a motion controller, and a data processing and
analysis system. Passive infrared detection system is mainly composed of optical lens group, multi-element infrared sensor, signal processing circuit and lithium battery power supply system.

With the rotation of the scanning system, the detection scanning line is spiral shape to scan the ground. In order to ensure the validity of the scanning system, the scanning angular velocity, the detection distance, the scanning angle and the flight speed are matched, and the minimum effective detection interval can not be greater than the width of the ground vehicle. Taking the ground vehicle coordinate system as the reference coordinate, the ground scanning trajectory parameter equation of the rotary infrared scanning detection system is Eq. (1).

\[
\begin{align*}
L \times \sin \theta \times \cos (\omega t) + (\vec{v}_r - \vec{v}_f) t \\
L \times \sin \theta \times \sin (\omega t)
\end{align*}
\]

In Eq. (1), relative velocity is \( \vec{v} = \vec{v}_r - \vec{v}_f \), detection time is \( t \).

3. Effect of infrared radiation characteristics of ground vehicles on signal amplitude

When the intrinsic radiation of ground vehicles and the radiation of reflected background reach the detector through atmospheric transmission and optical system conversion and generate the response voltage of radiation signal can be obtained as,

\[
V_S = \tau^* (\lambda) \tau_{air}^* (\lambda) \int_{\lambda_1}^{\lambda_2} I' \left\{ \Phi^* \times \omega \right\} A_0 R ( \lambda) d\lambda
\]

In Eq. (2), \( V_S \) is the signal voltage, the detection band of the infrared detection system is \( \lambda_1 - \lambda_2 \), \( A_0 \) is the area on which the target radiation area is mapped onto the detector sensitive surface. the detection distance between ground vehicles and infrared detection system based on air platform can be obtained as,

\[
L^2 = \frac{A_0 V_N \tau^* (\lambda) \tau_{air}^* (\lambda)}{V_S / V_N \sqrt{A_d N'}} \int_{\lambda_1}^{\lambda_2} I' \left\{ \Phi^* \times S \right\} d\lambda
\]

In Eq. (3), \( V_N \) is the effective value of noise voltage, \( A_d \) is the area of detector sensitive surface, \( \lambda \) is the spectral detection rate of infrared photodetector, \( \Delta N' \) is equivalent noise bandwidth.

4. Response analysis of ground vehicles radiometric projection size to infrared signal

The area size of the infrared radiation received by the infrared photodetector from the ground vehicles is a variable, resulting in the uncertainty of the energy contribution provided by the infrared feature area of the target to the infrared photodetector, it is closely related to the scanning angle of the detector, the height of the detecting system from the ground, the scanning speed of the rotating system of the detecting system and the change of the moving speed of the target. The pulse broadening feature of the signal received by the infrared photodetector contains the geometric size information of the target, which is a main reference index for target recognition and processing. Fig. 2, gives a schematic analysis of infrared radiation signal broadening under uncertain conditions.
Fig. 2 Analysis schematic diagram of infrared radiation signal broadening under uncertain conditions

In Fig.2, D is the theoretical diameter of target radiation region, \( AB \) is the chord length of the radiation area projected from the target radiation area to the detector field of view, O is the central point on the chord length of the projected area, \( \angle APB \) is the field of view of infrared photodetector, \( OP \) is the central line of view of the detector, The angle between \( PA \) and the center line of field of view of the detector is \( \beta_1 \), \( PB \) and the center line of field of view of the detector is \( \beta_2 \), and \( \beta_1 = \beta_2 \), \( \theta \) is the scanning angle of infrared photodetector. The pulse width response of infrared signal of infrared photodetector sweeping through the target heat source region is,

\[
V = \frac{t}{\omega} = \frac{\sin \beta_2}{\sin \theta \cos (\theta - \beta_2)} \frac{PC}{\pi f PO} \tag{4}
\]

In Eq. (4), \( V = CD \times \omega \), \( V = 2 \pi f PO \sin \theta \), \( PO = \sqrt{(PC/cos(\theta - \beta_2))^2 - (AB/2)^2} \).

5. The simulation and experimental analysis

5.1. Simulation analysis

According to the rotating scanning detection mechanism, when the infrared detector flies in one direction with velocity along one direction through the flight platform, its scanning line intersects with the ground. Suppose the maximum detection interval is \( \Delta R \leq 2m \), the diameter of detection area is \( 40m \), the detection altitude is \( H = 30m \), the detection angle is \( \theta = 30 \), the rotary speed is \( \omega = 4r/s \), and the flight speed is about \( v = 12m/s \). The scanning trajectory of an independent single element detector is obtained as shown in Fig. 3.
In Fig. 3, the black arrow represents the flight direction and the blue track represents the scan trajectory. When the armored vehicle exists in the main detection area of the front end indicated by the enlarged image, the detector will capture the infrared characteristic area of the armored vehicle. When the angular velocity and relative velocity are constant, the relationship between the response time and the response voltage of the signal under different detection distances is analyzed, as shown in Fig. 4.

![Rotary scanning trajectory of single element detector on the ground](image)

Fig. 4. Change of detection distance, relationship between signal response time and response voltage

In Fig. 4, it can be concluded that when the detection distance decreases, the amplitude of the signal response voltage increases and the response time of the signal increases. The change of response time corresponding to the change of target infrared feature area profile size is assumed as shown in Fig. 4(a). In Fig. 4(b), it can be seen that when the radiation characteristic region changes, when the angular velocity is constant, the speed of the detector sweeping through the infrared characteristic region is constant, and the signal response time will increase with the increase of the radiation characteristic region area.

5.2. Experimental analysis

In order to facilitate the acquisition of measurement data, using the experimental platform of rotating infrared scanning system, the civilian cars of 4.7 m long and 1.9 m wide is tested. Detection system verification experiment is shown in Fig. 5.
When the scanning angle is 30°, the radiation area of the power cabin is detected. With the increase of the detection distance, the area of the radiation area decreases gradually with the increase of the distance, and the radiation energy decreases accordingly. Fig.5(b) shows the energy attenuation caused by the change of radiation area when the detection distance is 5.4m and 33.6m. According to the detection performance of the rotary infrared scanning detection system, the radiation intensity at different detection distances and angles is detected by the rotary infrared scanning system, and the detection probability of ground vehicles is studied by setting the signal threshold. The signal amplitude and pulse width at the detection distance of 5.4 m and 33.6 m are analyzed, as shown in fig.6.

According to the comparative analysis of the signal characteristics in the radiation areas of figs.12 and 13, the target detection threshold can be set according to the voltage value and pulse width of the signal. When the detection distance is 5.4 m, the signal size is 9.3V, the pulse width of the signal is 6.3ms, and when the detection distance is 33.6 m, the signal size is 2.8V and the pulse width of the signal is 1.8ms. By studying the changing rules of these two eigenvalues, the detection rate of ground targets can be effectively improved.

6. conclusions
In this paper, the airborne infrared scanning imaging system for ground vehicles based on passive infrared detection is established. Through the simulation and experiment analysis, the energy released from the infrared feature area of ground vehicles decreases with the increase of detection distance when the parameters such as detection angle and rotation angular velocity are constant, but the characteristics
of signal amplitude and pulse width received by the detector are consistent. Establishing the system and theoretical model, the energy and size information of the target can be obtained effectively, which provides a scientific basis for distinguishing different targets with template matching recognition algorithm and improves the recognition ability of passive infrared detection system.

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