Application Research of Infrared Radiation Characteristic Measurement in Typical Target Recognition

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Abstract. To solve the problem of inadequate target recognition ability of traditional infrared measurement system in the test mission of multi-stage rocket/warhead, shrapnel, disruptor ammo and other targets, an infrared radiation characteristic measuring system is established based on the infrared radiation characteristic measurement principle, direct expansion source calibration and atmospheric parameters measurement. It has been proved that the method can make effective and reliable identification of typical infrared targets, which is of great significance for auxiliary decision-making of the infrared measurement systems.

1. Introduction

Infrared measurement system plays an important role in optical measurements, which can capture, track and measure the target effectively through its infrared characteristics. However, with the increase of targets species measured, the traditional infrared measurement system can not recognize the target effectively in real time, especially in the test mission of multi-stage rocket/warhead, shrapnel, disruptor ammo and so on, which greatly restricts its testing ability and can not meet the testing requirements.

In the infrared radiation characteristic measurement[1], the infrared radiation of the target and background is received by the infrared imaging system, transformed into an electrical signal by signal processing and its gray image is output after digitization. Thus, the infrared radiation characteristics and temperature distribution of the target and background can be obtained through inversion. By comparing the infrared radiation characteristics[2] of typical targets, effective identification can be achieved, and on this basis, the infrared measurement system is instructed to carry out effective tracking and measurements of main targets through the auxiliary decision-making control.

2. Basic principle of infrared radiation characteristic measurement

2.1 Principle of target radiation measurement

In atmospheric conditions, the infrared radiation characteristics of the target can be measured by the infrared measurement system. In the process of the target radiation reaching the infrared detector through atmospheric transmission, on the one hand, it will attenuate due to atmospheric transmission; on the other hand, the atmospheric radiation also overlays the target radiation and enters the detector together. Therefore, the model of target radiation characteristics under atmospheric conditions is as follows:

$$G = B + R(r_{am} \int_{\lambda}^{\lambda_{2}} r_{\lambda} L_{\lambda} d\lambda + L_{push}) \quad (1)$$
In the model, $G$ is the target gray value obtained by infrared measurement system; $B$ is the offset, because the system cannot be cooled to absolute zero, and the grayscale response of the thermal radiation of the optical system; $R$ is the target radiance response of the system; $\tau_{atm}$ is the average atmospheric transmittance and $L_{path}$ is the atmospheric path radiance; $r_\lambda$ is the relative spectral response function and $(\lambda_1, \lambda_2)$ is the operating band of the system; $L_T$ is the target radiance and $J_T$ is the radiation intensity of the target; $S$ is the cross-sectional area.

The target radiance response is different under different integration times of the detector. Within a certain gray range, the output gray value is linearly related to the target radiance, as shown in Figure 1.

![Figure 1. Gray value and target radiance relationship](image)

Therefore, in order to obtain the infrared radiance of the target from its gray value by inversion, spectrum calibration and radiation calibration should firstly be carried out for the infrared measurement system to get the relative spectral response function, the target radiance response and the offset. At the same time, the air parameters should be measured in real time during the mission to get the average atmospheric transmittance and path radiance.

### 2.2 Direct expansion source calibration

Expansion source calibration[3] at close range is the most commonly used radiation calibration method. In the calibration of the infrared system with this method, the blackbody is placed in front of the optical lens and covers the measurement system to reduce the influence of atmospheric radiation, absorption and scattering of the detection path on the calibration.

The basic principle is as follows: firstly, align the main optical axis of the infrared radiation measurement device with the blackbody center. And then, adjust the blackbody temperature and record the measured image after setting the band, integration time, attenuation plate position. The relationship between the blackbody radiance and the system response (gray) is as follows:

$$J_T = L_T \cdot S$$  \hspace{1cm} (2)$$

where $J_T$ is the radiation intensity of the target; $S$ is the cross-sectional area.

$$L_T = \frac{\varepsilon C_1 \lambda^{-5}}{\pi} \left( e^{c_2 \lambda T} - 1 \right)$$  \hspace{1cm} (4)$$

In it, $R$ is the system target radiance responsiveness to be calibrated; $G_O$ is the bias of the system itself; $\varepsilon$ is the system emissivity; $C_1$, $C_2$ are the first and second radiation constants.

By changing the operating temperature of surface source blackbody, multiple sets of effective blackbody radiance and corresponding system output values can be obtained. The target radiance responsiveness and the bias of the system can be obtained by linear fitting.

The calibration accuracy of the long-wave, medium-wave and short-wave infrared radiation characteristic measurement systems under typical integration time in the laboratory is shown in Table
1. Table 1. Calibration accuracy table of infrared radiation characteristic measurement system of different band

| the wave band      | integration time (μs) | blackbody temperature range (℃) | calibration accuracy |
|--------------------|-----------------------|---------------------------------|----------------------|
| long-wave infrared | 100                   | 25-100                          | 0.36%                |
| medium-wave infrared| 1000                  | 25-100                          | 1.31%                |
| short-wave infrared| 350                   | 100-150                         | 0.10%                |

2.3 Real-time modification of atmospheric parameters
The atmospheric parameter measuring equipment is used to measure various atmospheric parameters\(^4\), including visibility, temperature and humidity pressure, aerosol, water vapor distribution profile and so on. These parameters are provided to the atmospheric radiation transmission calculation software, to calculate the atmospheric transmittance and path radiation between the target and the infrared measurement system. The process is shown in Figure 2.

![Figure 2. Atmospheric parameter measurement process](image)

3. Measuring system configuration

3.1 Composition of the system
Based on the research above, the measuring system\(^5\) is configured by adding infrared radiation characteristic measurement related modules, including the target radiation characteristic measurement module, real-time task module, infrared radiation calibration module and atmospheric parameter measurement module to the infrared measuring system with the infrared camera and infrared image storage system, which is shown in Figure 3.

![Figure 3. Composition of the measurement system](image)

In the system, the real-time task module gives the control command of the camera and prevents
saturation and low gray level during the task. The atmospheric parameter measurement module measures the atmospheric parameters in real time during the task and calculates the atmospheric transmittance and path radiance with information such as pitch angle and slant distance provided by the photoelectric measurement system. The infrared radiation calibration module is used to control the blackbody temperature, optical system attenuation film and camera integration time, and to collect the calibration images. The target radiation characteristic measurement module is used to calculate calibration parameters and measure the target infrared radiation characteristics in real time.

3.2 Measuring process
In the process of multi-stage rocket separation, warhead-body separation, shrapnel separation and disruptor ammo throwing, the infrared measurement system tracks the target stably and collects the image continuously. The real time target radiation intensity can be obtained by calculating quantitatively the gray image combining with real-time atmospheric parameters. By analyzing the characteristics of different targets, the goal of target recognition can be achieved. Based on it, the main target can be tracked and measured effectively by the infrared measurement system guided by the auxiliary decision algorithm.

4. Experimental verification
In a certain type of ballistic missile test mission, the infrared radiation intensity of the warhead and the projectile body, the warhead and the fairing has been measured by the infrared radiation characteristic measurement system based on the infrared images captured by the infrared theodolite in real time. The results are shown in Figure 4 and Figure 5 respectively.

![Figure 4-1. Characteristics of the warhead](image1.png)

![Figure 4-2. Characteristics of projectile body](image2.png)

Figure 4. Infrared radiation characteristics of the warhead and projectile body

![Figure 5-1. Characteristics of the warhead](image3.png)
Figure 5-2. Characteristics of the fairing

According to the comparison, the movement law of the warhead after separation is relatively stable, and the movement has fixed axis rotation. Thus, the radiation intensity of the warhead presents a change of approximately sinusoidal law. The projectile body loses its power after separation, which is equivalent to free falling motion. Thus, its radiation intensity does not change much. Due to the explosion in the separation process, the fairing has irregular shape and irregular movement in the air, so its radiation intensity is also irregular.

5. Conclusion
In this paper, the target infrared radiation characteristic measurement system is constructed based on the research of the target infrared radiation characteristic measurement principle, direct expansion source calibration method and atmospheric parameters real-time measurement. In the test missions for targets such as multi-stage rocket/warhead, shrapnel, disruptor ammo, the purpose of target recognition is achieved through the analysis of the infrared radiation characteristics of different targets. The method has been proved effective by experiments, which is of great significance for the auxiliary decision-making of the infrared measurement system to track and measure the target effectively.

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