Infrared Physics and Technology 94 (2018) 102–109

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Regular article

Multi-band composite detection and recognition of aerial infrared point targets

Tian Kou*, Zhongliang Zhou, Hongqiang Liu, Yuanzhi Yang

Aeronautics Engineering College, Air Force Engineering University, Xi'an 710038, China

ARTICLE INFO

Keywords:
Multi-band signal
Detection probability
Recognition method
Optimized AdaBoost learning

ABSTRACT

Because of the low detection probability and recognition efficiency of the single-band signal of an infrared point target, the multi-band composite detection probability is analyzed and a multi-band recognition method is proposed. By using the binary hypothesis method, we can conveniently deduce the multi-band theoretical detection threshold and obtain the composite detection probability and false alarm probability. The numerical simulation results show that multi-band composite detection ability is superior to that of single-band. For the difficult classification between background and target spectral signals with serious interference noise in reality, this paper proposes a highly effective spectral signal recognition method based on the optimized AdaBoost algorithm. By virtue of the high classification accuracy of the AdaBoost algorithm, with the Pruning classifier as a basic classifier to be learnt, the proposed method abandons any abnormal data that seriously deviate from the mean value center of the correction classification data, the end result of which reduces the number of iterations and enhances the classification effect of the AdaBoost algorithm. Compared with other algorithms from test results, the optimized AdaBoost algorithm has higher recognition accuracy and quicker computation, and it reduces the sensitivity to noise to prevent the phenomenon of over-fitting.

1. Introduction

With the development of radar and infrared stealth technology, the detectability of aerial flight targets has been decreasing. Detection systems that depend on a single-band cannot satisfy the high probability requirement of stealth target detection [1,2]. Therefore, multi-band detection technology has become a topic of much current research. In contrast to single-band detection, multi-band detection provides an extension in the spectral domain and offers stronger anti-interference capability. Moreover, it can capture more detailed information corresponding to the desired target, realising difference information complementarity and greatly improving the detectability of aerial infrared targets [3,4]. Generally, infrared radiation from the aerial target is complex. In the direction of observation, the infrared signal peak, which is affected by the target attitude, height, distance, and speed, changes dynamically in the spectral domain. Therefore, the single-band signal often undergoes severe scintillation and complicates target detection in a cluttered background, easily resulting in a high false alarm probability during detection. However, a multi-band signal can reflect radiation characteristics in various wavebands, and even maintain a higher signal-to-noise ratio (SNR) for some wavebands, less influenced by changes in target speed, attitude, etc., which improves the detection probability [5,6].

Because of the increased detection distance, an aerial infrared target is weak and exhibits sub-pixel magnitude, along with no shape or structural information, and its SNR is very low, which presents a challenge for infrared weak point target detection in a complex environment [7]. Currently, there are many target signal recognition methods, including spatial filtering and statistical estimation methods [8–12]. These classical methods rely on a specific distribution assumption; then, in the case of known spectral noise statistical distribution, interference noise filtered out to improve the SNR and set a threshold value to judge the target signal, which leading to a better recognition effect. However, in the actual operational environment, it is not clear what the spectral noise statistical distribution is, and these methods simply focus on grey images or single band signals, so some important spectral information is lost [13]. Particularly under low SNR conditions, these classical signal recognition methods are greatly restricted.

Recently, some scholars have demonstrated that integrating multi-spectral or hyper-spectral features into research can improve the performance in many fields, such as image fusion, target classification and recognition, environmental monitoring and geological exploration [14–18]. Concerning pattern recognition, multi-band composite

---

* Corresponding author.
E-mail address: shanxiakkt@163.com (T. Kou).

https://doi.org/10.1016/j.infrared.2018.08.025
Received 15 June 2018; Received in revised form 15 August 2018; Accepted 29 August 2018

recognition is a binary classification problem, and classic classification methods include anomaly detection, clustering, support vector machine (SVM), Least squares method, and integrated learning. [19,20]. The anomaly detection method depends on given data samples. However, in the actual detection process, the point target signal is generated by sequence, so the anomaly detection cannot identify the separate signals. The clustering, SVM, and Least squares methods generally have a good recognition effect for linearly separable data, but for nonlinear data, these methods have a low recognition rate. Under high noise intensity with unknown statistical distribution, integrated learning provides a good solution; it can form a strong classifier using a proper combination of multiple weak classifiers. The AdaBoost algorithm is the most representative integrated learning algorithm. By altering the weight distribution of training data and making a weighted summation of various weak classifiers, the AdaBoost algorithm then becomes a strong classifier, and its purpose is to reduce classification error and realize all correct classification [21,22]. Although the AdaBoost algorithm has a high classification accuracy, the over-fitting phenomenon can easily occurs, which is not beneficial for identifying target signals [23–25].

In our previous work, we studied the spectral radiation characteristics of an aerial target and showed that the spectral signal peak dynamically varies in the spectral domain with a change in background and target attitude [26]. Based on these results, the current paper further studies multi-band composite detection and recognition for an infrared point target. The research is divided into two parts, one of which is primarily theoretical analysis and the discussion of multi-band detection probability and false alarm probability. The other part uses the improved integrated learning algorithm to classify multi-band signals and detect the target signal from the background noise signal.

The remainder of this paper is organized as follows. First, an analysis of multi-band composite detection probability is presented in Section 2. Then, a highly effective spectral signal recognition method based on the optimized AdaBoost algorithm is proposed in Section 3.1 and the experimental results and analysis are given in Section 3.2. Finally, the conclusion is provided in Section 4.

2. Multi-band composite detection probability

The most important qualities of an infrared detection system include detection probability, false alarm probability and operating range. However, the traditional calculation methods for each characteristic only consider a single-band infrared system, and a performance analysis method for composite detection by a multi-band infrared system is lacking. The infrared system is primarily used for the detection, classification, and recognition of small and weak targets, and the target radiation must have an appropriate SNR, to ensure higher detection probability and lower false alarm probability. Noise is the main factor affecting a missed detection or false alarm when detecting a target in a complex background. The single-band infrared system works at a lower threshold to noise ratio (TNR) to increase the detection probability, but at the same time, the false alarm probability is increased. When a multi-band infrared system is used for composite detection, even without a high SNR for each band signal, the detection probability of a suspected point target can be improved by mutual discrimination among multi-band signals, which then reduces the false alarm probability.

2.1. Detection threshold

Infrared radiation from an aerial target presents multi-band characteristics, and the multi-band signals contain two parts: target signals and noise signals, so the spectral signals detected by the detector can be expressed as [27]

$$s(\Delta\lambda) = v(\Delta\lambda) + \varepsilon(\Delta\lambda) \tag{1}$$

where $s(\Delta\lambda) = [s_1(\Delta\lambda), s_2(\Delta\lambda),...,s_n(\Delta\lambda)]$ denotes the detected multi-band signals, $\Delta\lambda$ is the integral band λ_i–λ_j with $1 \leqslant i < j \leqslant n$, $v(\Delta\lambda) = [v_1(\Delta\lambda), v_2(\Delta\lambda),...,v_n(\Delta\lambda)]$ denotes the multi-band radiation signals of the point target, and $\varepsilon = [\varepsilon_1, \varepsilon_2, ..., \varepsilon_n]$ is the vector of random interference noise. From our pre-studies, the spectral radiation of an airborne target is primarily concentrated in the 3–5 and 8–12 μm wavebands, so the multi-band signal model can be simplified as $s(\Delta\lambda) = [s_1(\Delta\lambda), s_2(\Delta\lambda)]$. Therefore, the spectral signals received by the detector have four cases, as follows:

1. $s_1(\Delta\lambda) = 0,\ s_2(\Delta\lambda) = 0$, no detected signals in either of the two wavebands;
2. $s_1(\Delta\lambda) = 0,\ s_2(\Delta\lambda) \neq 0$, detected signals only in the long waveband;
3. $s_1(\Delta\lambda) \neq 0,\ s_2(\Delta\lambda) = 0$, detected signals only in the medium waveband;
4. $s_1(\Delta\lambda) \neq 0,\ s_2(\Delta\lambda) \neq 0$, detected signals in both wavebands.

Considering that infrared point target detection is a binary hypothesis problem, the hypothesis can be assumed as follows:

H_0: $H_0 = P(s_1) \cap P(s_2)$, no target signal;
H_1: $H_1 = P(s_1) \cup P(s_2)$, target signal.

where $P(s_1)$ and $P(s_2)$ are the detection probabilities in the two wavebands. Generally, there are two major types of photoelectric detection systems, narrowband systems and broadband systems. This paper mostly discusses the narrowband system. When the spectral signals in the two wavebands pass the infrared optical system, the spectral signals can be written as $v_1(t) = a_1\cos(\varphi_1 t + \psi_1)$ and $v_2(t) = a_2\cos(\varphi_2 t + \psi_2)$, respectively. Therefore, the probability density of these two types of spectral signals are calculated as follows [26]:

$$f(s_1|H_1) = \frac{s_1}{\sigma_1^2}\exp\left(-\frac{s_1^2 + a_1^2}{2\sigma_1^2}\right)I_0\left(\frac{s_1 a_1}{\sigma_1^2}\right) \tag{2}$$

$$f(s_2|H_1) = \frac{s_2}{\sigma_2^2}\exp\left(-\frac{s_2^2 + a_2^2}{2\sigma_2^2}\right)I_0\left(\frac{s_2 a_2}{\sigma_2^2}\right) \tag{3}$$

where a_1 and a_2 are the amplitudes, and σ_1 and σ_2 are the noise standard deviations of the spectral signals in medium and long wavebands, respectively. $I_0(x)$ is the Zero-order Bessel function. When there is no target radiation signal, the amplitude of the target radiation signal is $a_1 = a_2 = 0$. Therefore, Eqs. (2) and (3) should be expressed as:

$$f(s_1|H_0) = \frac{s_1}{\sigma_1^2}\exp\left(-\frac{s_1^2}{2\sigma_1^2}\right) \tag{4}$$

$$f(s_2|H_0) = \frac{s_2}{\sigma_2^2}\exp\left(-\frac{s_2^2}{2\sigma_2^2}\right) \tag{5}$$

The false alarm probability of a single band is the probability that the noise signal exceeds the detection threshold of the target signal, and it can be written as [28]:

$$P(s_n|H_0) = P(s_n > a_{th}) = \int_{a_{th}}^{\infty}\frac{s_n}{\sigma}\exp\left(-\frac{s_n^2}{2\sigma^2}\right)\cdot \mathrm{d}s_n \tag{6}$$

where s_n is only the noise signal and σ represents the standard deviation of noise in any band. If s_{t+n} represents the target signal with noise signals, the probability of s_{t+n} exceeding the detection threshold a_{th} is the detection probability of a single band, as shown below:

$$P(s_{t+n}|H_1) = P(s_{t+n} > a_{th}) = \int_{a_{th}}^{\infty}\frac{s_{t+n}}{\sigma^2}\exp\left(-\frac{s_{t+n}^2 + a^2}{2\sigma^2}\right)\cdot I_0\left(\frac{s_{t+n}a}{\sigma^2}\right)\cdot \mathrm{d}s_{t+n} \tag{7}$$

By using the binary detection principle for a statistical signal, the likelihood ratio $\frac{P(s\mid H_1)}{P(s\mid H_0)}$ can be obtained. When the function likelihood ratio $\frac{P(s\mid H_1)}{P(s\mid H_0)} > \frac{P(H_0)}{P(H_1)}$, the hypothesis is judged as H_1; but, when $\frac{P(s\mid H_1)}{P(s\mid H_0)} < \frac{P(H_0)}{P(H_1)}$, the result is H_0. When $\frac{P(s\mid H_1)}{P(s\mid H_0)} = \frac{P(H_0)}{P(H_1)}$ is available, we