Selection of feature bands based on space-based detection

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Abstract: The space-based missile early warning system has different detection effect in different bands, and it is very necessary to select the appropriate detection band. In this paper, 11 kinds of missile plume spectra were studied and analyzed in the 2–5 μm. Many influential factors were considered, such as the plume height from the ground, the atmosphere and cloud radiation, atmosphere attenuation, etc.. Principle of selection is relatively stronger radiation of target, distance of target–to–earth from high to low, wave bands from more to less. The number of bands can be controlled by setting the threshold. Finally, the paper selected bands at the center wavelength of 2.99, 3.06, 3.12, 4.6, 4.62 μm. According to matching rules to fit out image that contains the characteristics of the target spectral, and signal-to-noise ratio (SNR) was analyzed for characteristic spectral image and full wavelength image. The results show that when the target reaches a certain height, SNR of characteristic spectral image is higher than that of the whole wavelength image.

Key words: characteristic spectrum; band selection; space-based detection; cloud and atmosphere

CLC number: E955 **Document code:** A **DOI**: 10.3788/IRLA201847.S117005

天基光谱探测特征波段的选择

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摘 要: 为解决天基特征光谱最佳探测波段的选择问题, 以 11 种导弹尾焰在 2.5~5 μm 处的光谱作为研究对象,综合考虑导弹距地面高度、大气传输、云层辐射、大气辐射等因素,设计出一种从多目标角度考虑的波段选择算法,以目标相对具有强辐射为原则,根据距地面高到低、波段从多到少的顺序进行选择,可通过设定阈值来控制所选波段个数,文中所选波段的中心波长分别为 2.99、3.06、3.12、4.6、4.62 μm。根据光谱图像拟合规则拟合出包含目标的特征光谱图像,从信噪比的角度对特征光谱图像和全波长图像进行分析,结果表明,当目标达到一定高度后,特征光谱图像的信噪比远大于全波长图像。

关键词: 特征光谱; 波段选择; 天基探测; 云层大气背景

收稿日期:2018-03-12; **修订日期**:2018-05-18

基金项目:国家自然科学基金青年科学基金(61703424)

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0 Introduction

Space-based detection has many advantages, such as wide range of detection, all-weather detection and real-time. It plays an irreplaceable role in missile early warning, and is an important part of the national defense system[1]. The missile plume contains a lot of high temperature components, such as H_2O, CO_2 and Al_2O_3, and these determine the characteristic whose spectrum has a peak at 2.7 μm and 4.3 μm, and has higher radiation intensity than the surrounding environment[2]. Using these features can improve the detection efficiency.

Detector using detection band has a direct impact on accuracy of the detection system, and the research problem of band selection has been paid attention. Ye calculated the different height of the atmospheric transmission rate of infrared radiation and atmospheric background based on MODTRAN software, and according to the contrast between target and background, chose a space-based infrared early warning satellite band [3]. Yuan took from a group bands of the missile plume spectral in 2–5 μm by using the improved band forward and backward interval partial least squares[4]. According to the infrared detection distance and dual band evaluation index, Xu calculated the space-based infrared detecting band effectively[5]. Based on the radiance flux contrast to typical liquid and solid missile plume spectrum as the research object, Liu calculated the appropriate space-based detection band[6]. According to the mixed gas (fuel), V.A according modeling factors emission characteristics, nozzle radiation law, through computer simulation, obtained a series of different parameters of the plume radiation of infrared spectrum, the infrared spectrum distribution in 2.7 μm, 4.3 μm[7]. All of these methods of band selection are based on one certain index, which can be selected for the single target at different heights.

There are methods applied to the classification of remote sensing images. Based on wavelet transform, Jing selected a band for target detection, which has been outstanding in the detection accuracy [8]. Wang proposed a method of two-step-band, first using a traditional method of choice, then according to the detection results to select band [9]. The methods are versatile and can improve the detection effect of the target, but these algorithms are not restricted by the real time, and can not be applied directly to the space-based detection system.

Based on these, the variety of missile plume radiation, height from ground, atmospheric transmittance, cloud and atmospheric radiation is considered, suitable band can be selected for a variety of space-based target.

1 Detection environment analysis

1.1 Atmospheric transmittance

Generally, atmospheric transmittance is determined by the absorption and scattering of the atmosphere. According to Lambert Bill′s law, we know[10]:

$$\tau(\lambda)=\tau_a(\lambda)\cdot\tau_s(\lambda) \tag{1}$$

where $\tau(\lambda)$ is the atmospheric transmittance at the wavelength of λ, and τ_a, τ_s represent the transmittance associated with atmospheric absorption and scattering respectively. Atmospheric transmittance varies with the different atmospheric density and atmospheric composition at different heights. For the convenience of calculation, the atmospheric transmittance of 0, 5, 10, 15, 25, 40 km is calculated by MODTRAN software, and it is used to show the following rules:

$$\tau(\lambda)=\begin{cases}\tau_0(\lambda) & 0\,\text{km}\leqslant h_m\leqslant 5\,\text{km}\\ \tau_5(\lambda) & 5\,\text{km}\leqslant h_m\leqslant 10\,\text{km}\\ \cdots & \cdots\\ \tau_{40}(\lambda) & 25\,\text{km}\leqslant h_m\leqslant 40\,\text{km}\\ 1 & 40\,\text{km}\leqslant h_m\end{cases} \tag{2}$$

where τ_0 (λ), τ_5 (λ) ⋯ represent the atmospheric transmittance of 0 km, 5 km⋯ respectively.

Figure 1 shows the atmospheric transmittance of 0, 5, 10, 15, 25, 40, 60, 80 km, and the measurement accuracy is 2.499 nm. In the figure, the atmospheric transmittance of 0, 5, 10 km is similar, the main difference is that the transmittance increased near 2.7 μm, 4.3 μm with increase of height, 15 km and 25 km atmospheric transmittance similar to 80 km 40 km, the remaining band atmospheric transmittance is about 1.

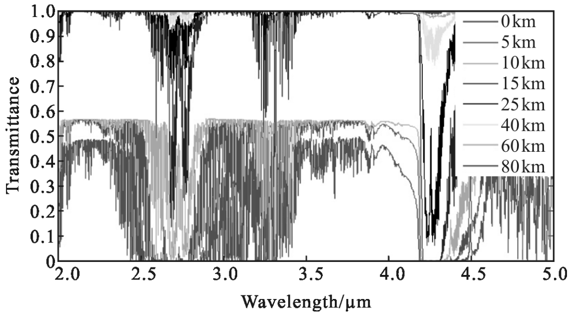


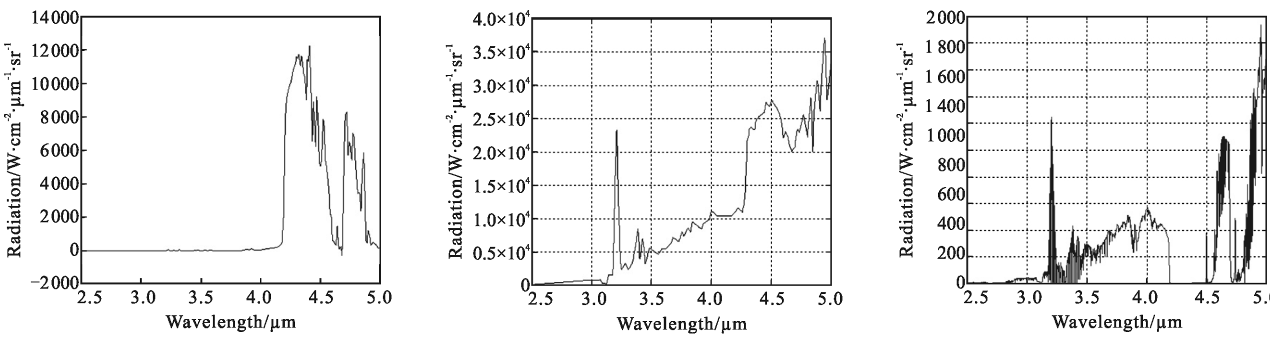
Fig.1 Atmospheric transmittance at different altitudes

1.2 Noise analysis

The earth background includes ocean, land, grassland, mountain range, factory, volcano, atmosphere, cloud and so on. The main interference sources of different detection bands are different. In this paper, the study band is 2.5–5 μm, so the noise is only radiation of atmospheric radiation and cloud.

The radiation of the atmosphere mainly comes from the reflection and scattering of strong radiators. Strong radiation contains the sun, missile plume[10]. Its radiation is very low in relative background. Figure 2(a) is the spectral curve of the atmosphere at 2.5–5 μm.

Cloud contains a large number of water molecules. After absorbing solar energy, it has certain energy, radiating energy in all directions, and reflecting the sunlight, forming its unique spectrum. The cloud spectrum has strong forward scattering in the near infrared band. So the position of detector, cloud and sun have a great influence on the spectrum of cloud. Figure 2 (b) is spectrum of cloud under a state near infrared, cloud height from the ground is about 10 km. Spectrum after attenuation is shown in Fig.2(c).



(a) Spectrum of atmospheric (b) Spectrum of cloud without atmospheric attenuation (c) Spectrum of cloud through atmospheric attenuation

Fig.2 Spectrum of background

1.3 Target analysis

The missile plume has character of high temperature and large area, so it has strong radiation compared to the surrounding environment, and it is easily detected[11]. Figure 3 is a typical missile plume spectrum in 2.5–5 μm, which contains the solid and liquid wake spectra of different fuel components. According to the Eq. (2), different height of the missile plume spectrum after atmospheric attenuation is shown in Fig.4, the plume spectral data is normalized. From observation, the plume spectrum of

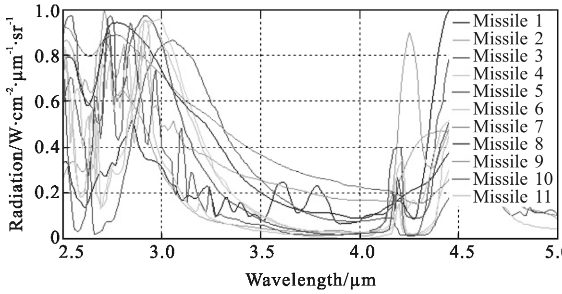


Fig.3 11 kinds of missile plume spectra without atmospheric attenuation

atmospheric transmission still has certain characteristics, if not considering real-time, plume spectrum can be ensure by choosing enough multi-band. According to the characteristics of the missile plume, the radiation level of missile plume is 10^6, which becomes 20 after the atmospheric transmission. That is, when the detector sensitivity is high enough, the missile on the ground can also be detected, but it is easy to submerge in the background. For better detection of targets, research can be conducted from three perspectives:

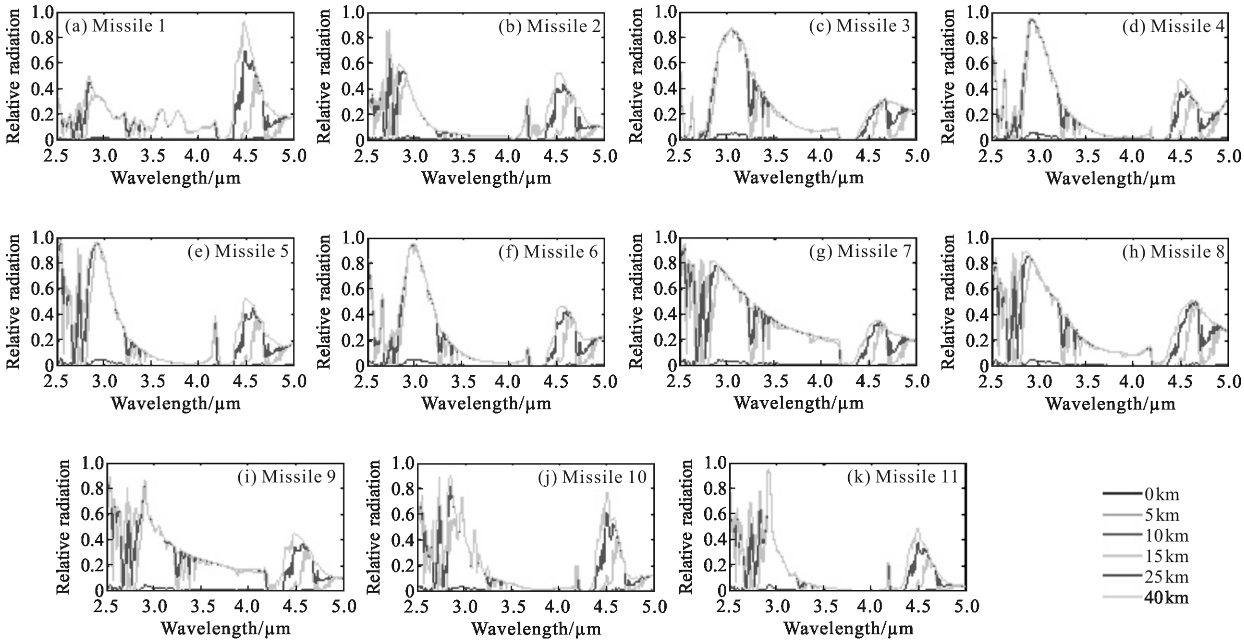


Fig.4 Missile plume spectrum through atmospheric attenuation at different heights

(1) Expand the range of band selection: that is, selecting the characteristic wave band of missile plume from the band beyond 2–5 μm, and choosing the band with strong radiation and weak radiation background.

(2) The improvement of hardware performance: when the detection band is narrow enough, the unrelated noise can be filtered through the hardware measures directly to achieve the detection purpose.

(3) Effective algorithm design: based on the hardware, the effective algorithm of target detection should be designed so that the enhance target and weaken the background.

2 Feature band selection

Generally, according to the operational task of ballistic missile, the device of thrust size is set up. The radiance intensity of different size of the inference device is different. In order to make the selected band universal in space-based detection, the missile plume spectrum is normalized.

Band selection can be divided into horizontal and vertical parts, lateral part of the missile plume spectrum of the same height of different types are analyzed, and then the best band height is selected. Longitudinal section is based on various types of missile plume spectrum from the ground at different heights to choose the best band. The concrete steps of the algorithm are as follows:

(1) According to Eq.(2), the spectrum of the 40-km missile plume is calculated after atmospheric transmission. Then select the bands with strong radiation compared to the background, Band-set is A.

(2) Using the same way, all the missile plume spectral radiations from the ground 25, 15, 10, 5, 0 km can be calculated, and can be selected corresponding characteristic bands of high altitude. The selected characteristic band sets were respectively recorded as B, C, D, E and F.

(3) Finally, the intersection of A, B, C, D, E and F is obtained as the final feature band set, and its mathematical expressions are as follows:

$$B_{\text{selected}}=A\cap B\cap C\cap D\cap E\cap F \tag{3}$$

The characteristic bands are selected in descending order of missile height, and the number of selected bands is much smaller. The algorithm flow chart is shown in Fig.5.

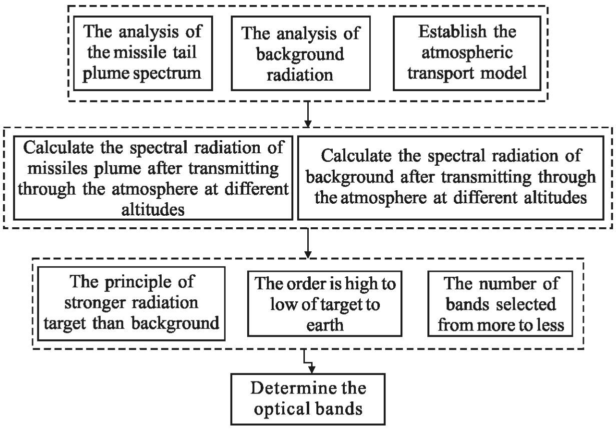


Fig.5 Flow char of band selection

3 Results and analysis

According to the method of band selection, and using the 11 kinds of missile plume spectrum in Fig.4 as the researched objects, the selected band center are 2.99, 3.06, 3.12, 4.6, 4.62 μm. Using the method of characteristic spectral image fitting in document[12], the spectrum images of the selected band are drawn out. Figure 6 is the detection effect map at 25 km. The target is 11×11 pixels. The number of each column is the same, Fig.6(a)–(e) is a set of fitting images with 2.99, 3.06, 3.12, 4.6, 4.62 μm. The observed images show that most of the missile exhaust plume can be detected at selected bands, and a few plume is not detected in individual bands. From the aspect of SNR, the advantages of spectral bands of selected bands are analyzed. The expression of signal to noise ratio represent as:

$$\mathrm{SNR}=\frac{|U_t-U_b|}{\delta_b} \tag{4}$$

where U_t is the gray mean value of images containing targets, U_b is the mean value of background gray, and δ_b is the standard deviation of background gray.

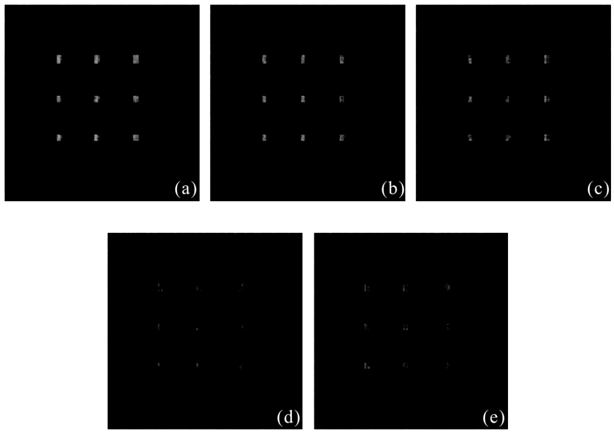


Fig.6 Images of characteristic spectrum at 25 km

Assuming that the height of the cloud is fixed to 10 km, that is, when the target is not synchronized, the background radiation intensity is certain. According to Eq.(4), the SNR of the infrared image and the characteristic spectral image with 2.99 μm as the center of the band is calculated, and the results are shown in Tab.1.

Tab.1 SNR of the fitted image

		U_t	U_b	δ_b	SNR
Feature band image of 2.99 μm	40 km	0.639 6	0	0.05	12.792 0
	25 km	0.624 2	0	0.05	12.484 0
	15 km	0.002 1	0	0.05	0.042 0
	5 km	0.000 1	0	0.05	0.002 0
	0 km	0.000 1	0	0.05	0.002 0
Image of 2–5 μm	40 km	8.500 1	4.959 6	2.037	1.738 1
	25 km	7.999 1	4.959 6	2.037	1.492 1
	15 km	7.358 0	4.959 6	2.037	1.177 4
	5 km	4.962 6	4.959 6	2.037	0.001 5
	0 km	4.959 6	4.959 6	2.037	0.000 0

From Tab.1, we can know that in the characteristic wave band with 2.99 μm as the center, the target has a higher SNR from the ground 40 km and 25 km, and SNR is greatly reduced from below 15 km. In the 2–5 μm, with the goal of increasing the height of the SNR is increased, especially when the target distance 15 km above the ground, the characteristic bands of SNR is far higher than the full band. Below 15 km, the advantage of characteristic wave is not reflected, which further illustrates the limitations and the choice of bands should not be limited to 2–5 μm.

4 Conclusion

The selection of early-warning detection band is great significance for national defense system. Starting from the missile plume, the spectrum of missile plume is analyzed, choosing 11 typical missile plume spectrum as the research object, and using software of MODTRAN to calculate the level of atmospheric transmission rate of different height from the ground. The band is selected according to principle that plume has stronger radiation than background. The number and the width of band are controlled by setting the corresponding radiation threshold. Finality 2.99, 3.06, 3.12, 4.6, 4.62 μm are selected as spectral band in 2.5–5 μm. The method of selection band has a certain value of engineering application, but there are still some shortcomings. First, the selection of typical missile plume is difficult, the number and type of selection will directly affect the detection effect. In addition, the model of atmospheric transmission rate is difficult to establish because of the different climate and environment in different parts of the world. The above problems can still be the focus of future research.

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