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Multiscale random projection based background suppression of infrared small target image

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HIGHLIGHTS

- We present a background suppression method based on multiscale random projection.
- Nonsubsampled pyramid is applied to separates the background and targets.
- The proposed method can not only efficiently reduce the spatial redundancy but also preserve target information.
- Both background suppression and target enhancement can be achieved by computing Mahalanobis distance in the proposed method.

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ABSTRACT

The heavy clutters background in a single infrared image containing small targets is difficult to be efficiently suppressed using the traditional methods. To overcome this difficulty, a novel infrared image background suppression method based on multiscale random projection is proposed in this paper. On the one hand, using nonsubsampled pyramid transform that decomposes the original infrared image into a low-frequency subband and a series of high-frequency subbands, the proposed method separates the background and targets from the original infrared image. On the other hand, due to a subband image cube is formed by concatenating together all the high-frequency subbands and a random projection is applied to the image cube, the proposed method can well preserve target information and reduces the spatial redundancy of the target and background information. Experimental results on three real infrared image sequences under different clutters background demonstrate that the proposed method is efficient and can obtain better performance than other methods for background suppression of infrared small target images.

1. Introduction

Infrared small target detection is one of the key techniques in infrared search and track (IRST) system [1]. The detection precision directly affects the performance of IRST system. If the heavy clutters such as cloud clutters exist in infrared images, the small targets contained in infrared images will be submerged with the complex clutters background. What's more, the small targets lack the information of concrete shape and texture since the long imaging distance. Thus, small target detection in complex infrared clutters background becomes a difficult and promising problem. Considering the characteristics of the complex infrared clutters background discussed above, infrared clutters background suppression has become critical in the process of small target detection. To do this, researchers have done many correlative research efforts.

A large number of background suppression methods [2–4] have been proposed in literatures. These methods can be broadly grouped into three families [2,5]: spatial filter-based methods, temporal filter-based methods and transform domain-based methods. The spatial filter-based methods have a relative long history, such as the max-mean\max-median filter [6], the morphological method [7–9], two-dimensional least mean square filter [10], the bilateral filter [11], bilateral two-dimensional minimum mean square error [12], background estimation method based on non-parametric regression [13] and other methods based on biological vision [14–16]. These methods are based on an assumption that the background pixels are spatially correlated and the target pixels

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are the opposite. Thus, the predicted background can be obtained by a spatial filter. And the clutters background can be easily suppressed by subtracting the predicted background from the original image. However, this kind of method usually leads to a high false-alarm rate for complex varied clutters background.

In the past few years, the background suppression methods based on temporal filter-based have become a popular topic. Unlike the spatial filter-based methods, this kind of method assumes that the background pixels are stationary in temporal domain and the moving target pixels are non-stationary, such as triple temporal filter (TTF) [17], Mexican hat continuous wavelet transform (CWT) [18], infinite impulse response (IIR) [19] and temporal difference projection [3]. These methods suppress the background clutters via the trajectory characteristics of targets in temporal domain and obtain relative good effect in some cases. However, suppression performance decreases dramatically for the real infrared images since their backgrounds are usually not stationary.

In addition, the transform domain-based methods have attracted many researchers' attention. Despite of the advantage over easily separating the targets and clutters background into high-frequency subband and low-frequency subband, respectively; and suppressing background by removing the low-frequency subband, there still has disadvantage is that these methods cannot efficiently suppress the clutters background when edges are decomposed into high-frequency subband. Likewise, these methods also need more time to decompose the original image, which makes the transform domain-based methods not be able to work better in practical applications. Such as the methods based on Butterworth high-frequency filter [20] and wavelet transform [4,21].

Based on the drawbacks of the spatial filter-based methods, temporal filter-based methods and transform domain-based methods discussed above, this paper proposes a novel method to suppress the infrared image clutters background through the combination of the feature of high-frequency subbands decomposed by nonsubsampled pyramid transform [22,23], containing the main information with the similarity estimation in random projection domain [24]. The original infrared image is decomposed into a low-frequency subband and a series of high-frequency subbands by nonsubsampled pyramid transform which is an efficient approach to complete the preprocessing about the infrared image background suppression and target enhancement. Due to the difference between targets and background, we use random projection method [25] to compress the high-frequency subbands to reduce the redundancy and maintain the main information of targets. Furthermore, Mahalanobis distance [26,27] is also used to estimate the similarity between targets and background pixels to achieve the background suppression and target enhancement. The experimental results show the efficiency and reliability for background suppression.

The paper is organized as follows. In Section 2, the nonsubsampled pyramid transform and random projection principle are briefly reviewed. The proposed infrared background suppression method is discussed in detail in Section 3. Section 4 concretely describes the experiment results and performance analysis. Finally, Section 5 concludes this paper.

2. Related works

2.1. Nonsubsampled pyramid transform

Nonsubsampled pyramid transform (NSP), a signal decomposition algorithm, is widely used in the field of image processing. NSP is a shift-invariant filtering structure, which is achieved by 2-D two-channel nonsubsampled filter banks.

In fact, the multiscale decomposition of NSP is similar to that of the Laplacian pyramid. Such expansion is conceptually similar to the 1-D nonsubsampled wavelet transform computed with the *àtrous* algorithm, and has $K+1$ redundancy, where K is the number of decomposition scales. The equivalent filter at each scale is calculated as:

$$\widetilde{H}_n(z) = \begin{cases} H_1(z^{2^{n-1}I})\prod_{i=0}^{n-2} H_0(z^{2^i I}), & 1 \leqslant n \leqslant K \\ \prod_{i=0}^{n-2} H_0(z^{2^i I}), & n = K+1 \end{cases} \tag{1}$$

where $H_0(z)$ and $H_1(z)$ denote the lowpass filter and highpass filter at the first scale respectively. The filters for subsequent scale are obtained by upsampling the filters of the first scale with the sampling matrix $\boldsymbol{D} = 2\boldsymbol{I}$, where $\boldsymbol{I}$ is an identity matrix of the second-order. Fig. 1 shows the NSP decomposition with $K = 3$ scales.

An image can be decomposed into one low-frequency subband and one high-frequency subband at each NSP decomposition scale. The subsequent NSP decomposition scales are performed on the low-frequency component available iteratively to capture the singularities in the image. As a result, after K-scale NSP decomposition, it can produce $K+1$ subbands with the same size as the original image that include one low-frequency subband and K high-frequency subbands at different scales. In order to visually illustrate the results decomposed by NSP, Fig. 2 gives an experimental result of three-scale NSP decomposition for an infrared image.

2.2. Random projection

Random projection is a simple and powerful dimensionality reduction tool for high-dimensional data, which can preserve the main information of original high-dimensional data by low-dimensional data and avoid causing a distortion of the high-dimensional data. We use random projection to process the image cube constructed by concatenating all the high-frequency subbands to achieve high-dimensional data represented by low-dimensional data, which can reduce the amount of data and still preserve almost all of the information of its corresponding high-dimensional data. The random projection model is shown in Fig. 3.

To describe the proposed algorithm easily, we assume a random matrix $\boldsymbol{\Phi} \in \mathbb{R}^{S\times K}$ which can project data from the high-dimensional image space $X \in \mathbb{R}^K$ to a low-dimensional image space $Y \in \mathbb{R}^S$. It is defined as:

$$Y = \boldsymbol{\Phi}X \tag{2}$$

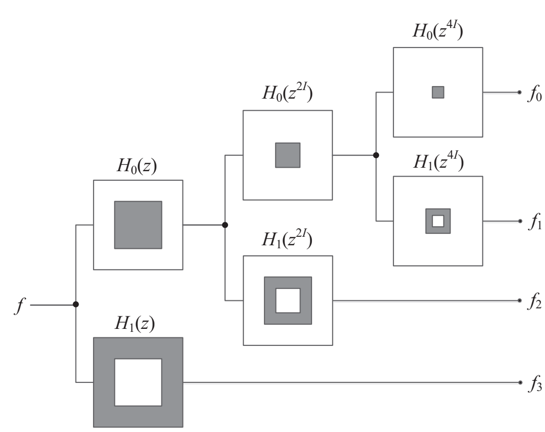

Fig. 1. Three-scale NSP decomposition.