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Small target detection based on accumulated center-surround difference measure

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HIGHLIGHTS

- We propose novel method to detect infrared small targets in heavy clutter.
- The method can distinguish target region and inhomogeneous region.
- The method needs no prior knowledge and no sensitive parameters.

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ABSTRACT

Small target detection is a critical problem in the Infrared Search And Track (IRST) system. Although it has been studied for years, there are some difficulties remained due to the clutter environment such as the cloud edge and the horizontal line. In the homogeneous area such as sky, cloud-inner area and sea surface area, target can easily be detected, but in heterogeneous area which contains cloud edge, sky-sea line the target may be falsely detected. This paper proposes a novel method called accumulated center-surround difference measure to detect infrared small target in heavy clutter. Each pixel's accumulated center-surround difference measure is computed by using sliding window manner. The measure can effectively distinguish target region and heterogeneous region. Experimental results show our method achieves better performance.

1. Introduction

Small target detection is a critical problem in the Infrared Search And Track (IRST) system. Although it has been studied for years [1–5], there are some difficulties remained. The reasons are as follows: first, features such as texture and color are unavailable for small targets when they are far away from the infrared sensor. Second, heterogeneous areas such as cloud edge and sky-sea line may be falsely detected as small targets.

Background estimation based small target detection method is widely studied in recent years [6–9]. These methods detect small targets in the residual image which subtracts the estimation image from original image. The detection performance depends on how well the background estimation image can achieve. The 2-D least mean square (TDLMS) method [6] minimizes the difference between an input image and a background image that is estimated by the weighted average of neighboring pixels. The TopHat method [7] estimates background by a morphological opening operator with structure element.

Existing background suppression methods for single-frame infrared image are mainly based on the filtering methods [10,11]. The LS-SVM [11] method uses filter templates, which can suppress most part of the correlative background but may be easily interfered because of the strong fluctuation of background clutters.

Recently, a small target detection algorithm based on sparse representation has been proposed [12]. They modeled small infrared targets by Gaussian intensity model for dictionary generation, and solved a sparse $l0$-minimization problem at any candidate point of target when a detection window scans over the test image.

The main drawback of conventional filtering based methods for small target detection is they could not guarantee sufficient suppression ability towards those high frequency components belonging to background, such as strong corners and edges. In recent years, a method based on local connectedness constrains [13] was proposed to overcome such problems.

Heterogeneous areas such as cloud edge and sky-sea line make small target detection more difficult. These methods may achieve

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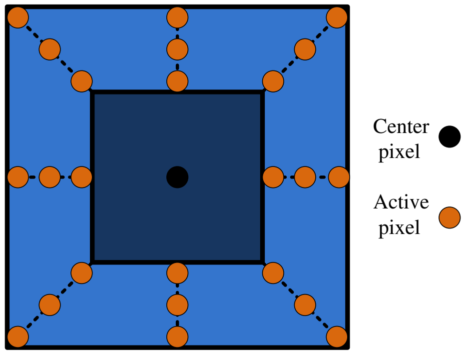

Fig. 1. Illustration of calculating accumulated center-surround difference measure.

good results on simple background, but not on heavy clutter background. The main reason is they cannot distinguish small targets from heavy clutter effectively. We propose a novel method called accumulated center-surround difference measure to detect infrared small targets in heavy clutter. When compared with TDLMS [6], TopHat [7], LS-SVM [11], SP [12], LCC [13], our method achieve better performance, especially in the heterogeneous area.

2. The proposed method

We propose a single-frame infrared small target detection method. We calculate each pixel's accumulated center-surround difference measure. A measure map is obtained, which indicates the probability of a pixel belonging to target regions. We then can detect small target by implementing a proper threshold.

Generally, the IR image model can be formulated as:

$$f(x,y) = f_T(x,y) + f_B(x,y) + n(x,y) \tag{1}$$

where f, f_T, f_B, n and (x,y) are IR image, target image, background image, random noise and pixel's coordinate, respectively. n is assumed to follow Gaussian distribution with mean 0 and variance σ^2 [8].

According to (1), IR image can be divided into 3 different components: target region, homogeneous region and inhomogeneous region. Homogeneous region usually locates inside the cloud, the sea surface and the sky, whereas inhomogeneous region may appear in the sky-sea line and cloud edge. Conventional background estimation method may regard inhomogeneous region as target mistakenly, because features of inhomogeneous and target region are highly similar. Based on the observation above, we propose accumulated center-surround difference measure to distinguish target region and inhomogeneous region.

Fig. 1 describes the proposed accumulated center-surround difference measure for a certain pixel (i,j) . An outer window of the size $N*N$ and an inner window of the size $M*M$ are defined around the reference pixel. Along 8 orientations (i.e. $0^\circ, 45^\circ, \ldots, 270^\circ, 315^\circ$), the accumulated difference measurement is carried out respectively.

For example, along 0° orientation the accumulated center-surround difference is:

$$\sum_{\substack{ii=i \\ j+M/2 \leqslant jj \leqslant j+N/2}} \tau[(ii,jj),(i,j)] * |I(ii,jj) - I(i,j)| \tag{2}$$

where $\tau(\cdot)$ can be certain monotone increasing function. In this paper,

$$\tau[(ii,jj),(i,j)] = 1 - e^{-c*\|(ii,jj)-(i,j)\|_2^2} \tag{3}$$

(i,j) is the coordinate of the central pixel (i.e. the reference pixel), and (ii,jj) is active pixel's coordinate. $I(\cdot)$ represents pixel's intensity. Here M is a constant smaller than N. Accumulated center-surround difference measure can distinguish target region and inhomogeneous region. Fig. 2 represents results of accumulated

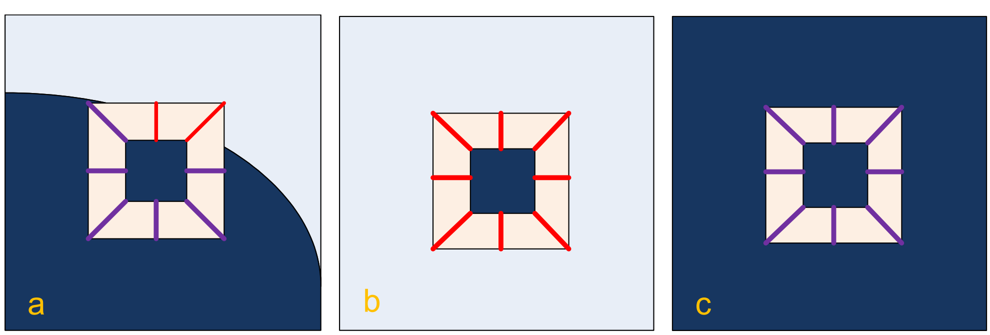

Fig. 2. Results of accumulated center-surround difference in 3 different pixels.

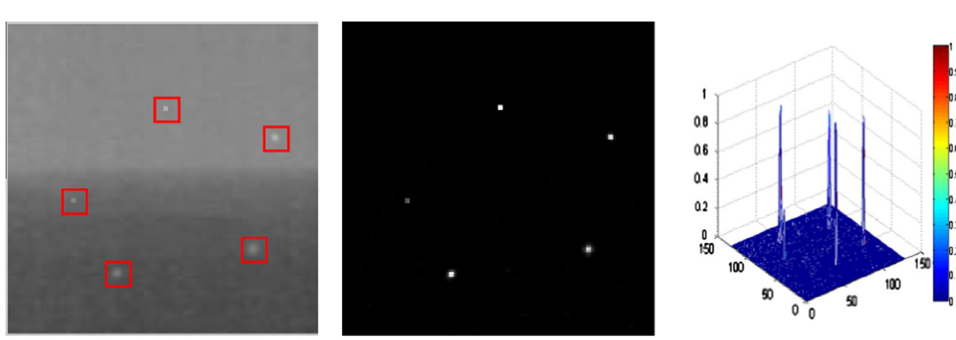

Fig. 3. An IR image and its accumulated center-surround difference measure. From left to right: original image, accumulated center-surround difference measure and its 3d-plot.