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Semi-supervised learning based edge-preserving background estimation for small target detection

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HIGHLIGHTS

- Semi-supervised learning is used in background estimation for small target detection.
- Geometrical structures in patch image are described using Graph Laplacian.
- Graph Laplacian regularization is incorporated in the semi-supervised learning model.
- Bilateral kernel is utilized to realize background estimation method.

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ABSTRACT

The edges in infrared image will cause false alarms in small target detection. So a novel edge-preserving background estimation method is proposed in this paper for single frame small target detection. First, we propose a novel background estimation method based on semi-supervised learning, and the Graph Laplacian regularization is utilized in this model to preserve accurate edges in estimated background image. Then, the bilateral kernel is utilized to realize background estimation method. At last, edge-preserving estimated background is eliminated from original image to get difference image which is used as foreground to detect the small target. The experiment results demonstrate that our proposed method can achieve edge-preserving background estimation significantly and efficiently, and get better small target detection results.

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1. Introduction

Infrared small target detection is widely used in many applications, and lots of small target detection methods have been proposed in recent years. However, the infrared images with complicated background and the low signal clutter ratio (SCR) usually lead to serious false alarms in small target detection. So small target detection in the infrared images with complicated background, especially infrared image with urban background, is a challenging work.

Lots of background estimation methods for small target detection are proposed to segregate background and foreground for small target detection in last decade [1–12]. In these background estimation methods, local gray level distribution are used to predict background [1]. The background gray value of a pixel in image is predicted by its neighborhood gray value distribution, and it can get good prediction results in flat background region. However, edges in background usually are smoothed using this model. Addressing this problem, serval edge-preserving background estimation methods are proposed. The edge direction is detected by analyzing the surrounding blocks around current background estimation window [13,14]. Then two-dimensional least mean square (TDLMS) is adjusted to the direction of edge to preserve edges. But if edges with various directions exist in the estimation window, such as at corner, they will get bad edge-preserving results. And modified mean filter in [15] is used to preserve the horizontal edge, this method preserves edges along preferred directions. Unfortunately, the infrared images with complicated background generally contain zig-zaged edges and junction of edges. What's more, the TDLMS filter based background estimation method aims to minimize the mean square error in image patch [13], and the mean square is L_2 norm which is well known to be sensitive to outliers. This sensitivity causes these background estimation methods to produce visually unsatisfying results [16]. If the small target exists in one patch, the estimated background will bias and affect the SCR. Edge-preserving ability of bilateral filter is also used to

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estimate the background [17,9] and these two methods get better results using multi-frames infrared images. These methods require the background of infrared image unchanging or need image motion compensation, these requirements are hard to meet in practice. So the effective and robust edge-preserving background estimation method for single frame small target detection is still needed.

In order to deal with problems, we propose a novel semi-supervised learning based edge-preserving background estimation model for small target detection. First, the accurate edge estimation ability will be specially taken into account when we design clutter background estimation method. And we both know that pixels on the same graph structure have more probability to share similar gray value in infrared image. So this feature of infrared image can be used in background estimation to preserve accurate edges. And this similarity feature of graph structure is independent on directions of graph structure, so it is capable of preserving edges with different directions in background estimation window. This similarity feature of graph structure in image data domain is used in Graph Laplacian regularization model to preserve structures for image denoising and image restoration [18,19], which achieved good result, and the Graph Laplacian regularization is added in our model to preserve edges in infrared image. Then, in order to avoid the drawback of L_2 norm in background estimation model, only part of pixels in patch image are selected as labeled samples in semi-supervised learning model to predict the background in our method. So our proposed background estimation based on Graph Laplacian regularized and semi-supervised learning is capable of getting a precise edge estimation and precluding the effect of small target on background estimation.

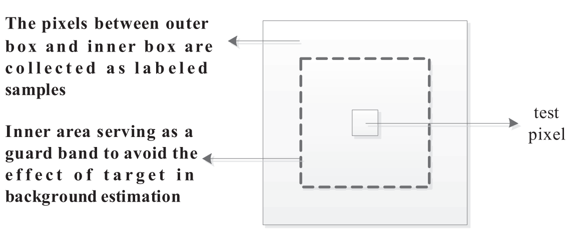


Fig. 1. The structure usually used in background estimation.

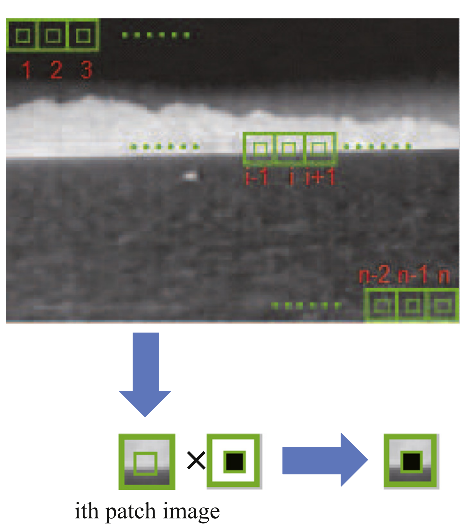


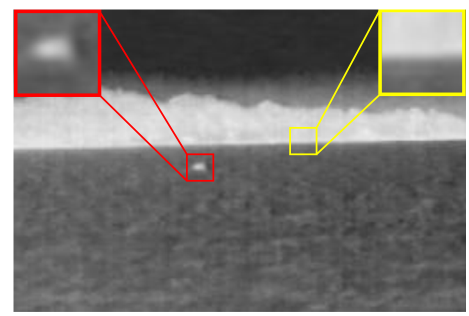
Fig. 2. Construction of patch image and labeled samples.

We will introduce Graph Laplacian regularized semi-supervised learning model in Section 2. Furthermore, in Section 3, the bilateral kernel based optimization scheme is detailed. The small target detection method based on our edge-preserving background estimation model will be described in Section 4. Section 5 presents experimental results to validate our theoretical solution.

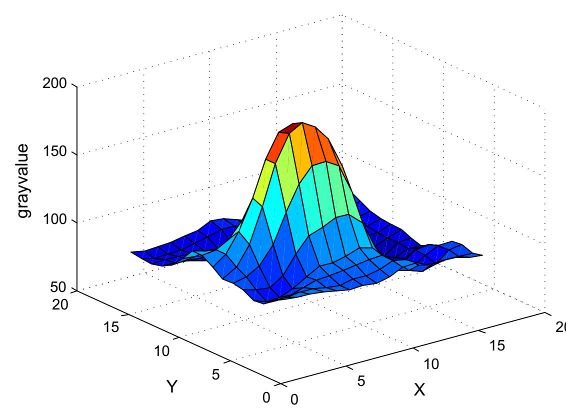
2. Edge-preserving background image estimation

In small target detection, infrared image generally can be divided into three components: target image, background image, and noise image.

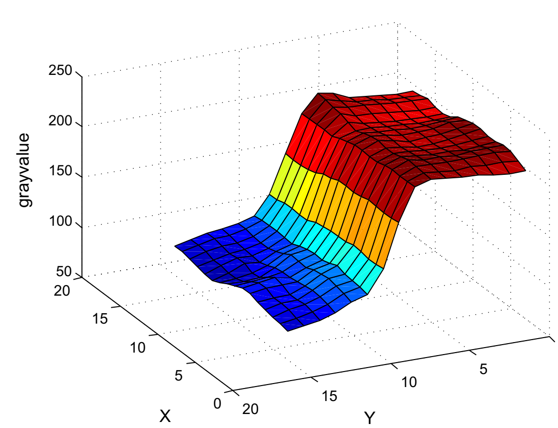
$$G(\mathbf{u}) = T(\mathbf{u}) + B(\mathbf{u}) + N(\mathbf{u})$$



(a) the red patch contains small target, the yellow patch contains one edge.



(b) target patch grayvalue distribution



(c) edge patch grayvalue distribution

Fig. 3. Grayvalue correlation difference between small target and edge in patch image. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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