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High-Boost-Based Multiscale Local Contrast Measure for Infrared Small Target Detection

Yafei Shi, Yantao Wei, Huang Yao, Donghui Pan, and Guangrun Xiao

***Abstract*— Robust and efficient infrared (IR) small target detection plays an important role in image processing for IR remote sensing. In order to detect the IR small target with high detection rate, low false alarm rate (FAR), and high detection speed, a novel method called high-boost-based multiscale local contrast measure (HB-MLCM) is proposed in this letter. First, improved high boost filter is proposed to enhance the high frequency signal where the target may appear and suppress the low frequency signal. Then, a simple MLCM is proposed for further enhancing the target and suppressing the background. Finally, a simple and adaptive thresholding method is used to segment targets from the contrast map. Experimental results on three real image sequences with various typical complex backgrounds demonstrate that the proposed method can effectively detect the target with faster speed, higher detection rate, and lower FAR compared with the state-of-the-art methods.**

***Index Terms*— Improved high boost filter (IHBF), infrared (IR) image, local contrast measure (LCM), small target detection.**

I. Introduction

In RECENT years, infrared (IR) small target detection as a key technology has been widely used in many fields, such as early warning system, precision guided weapon, missile tracking system, and maritime surveillance system [1]–[3]. On the one hand, the targets in IR images are mainly concentrated in a small gray point, lacking obvious shape and texture features [4]–[6]. On the other hand, IR small target is surrounded by complex background clutters, and the contrast between the targets and its corresponding surrounding background clutters is usually low [3], [7], [8]. Hence, these effects make the IR small target detection a challenging task [9], [10]. Now, many state-of-the-art methods have been proposed for IR small target detection. However, when facing highly heterogeneous backgrounds, these methods cannot perform very well.

Recently, imitating the mechanisms of human visual system (HVS) to design a small target detection method has aroused the interest of researchers [1], [11], [12]. According to the attention mechanism of HVS, the absolute intensity of visual signals is not the most important factor in attention system, but the contrast and difference between targets and their corresponding surrounding backgrounds [13]. And the HVS is to use this kind of contrast mechanism to find the interested object from the complex backgrounds. Many small target detection methods have been proposed based on the contrast mechanism of HVS [1], [3], [11]–[15]. These methods, however, still exist with many deficiencies. For example, Chen *et al.* [1] proposed a local contrast measure (LCM) method that uses the difference between the target region and corresponding surrounding areas. But it has limited ability to suppress background clutters. Afterward, Han *et al.* [12] introduced an improved LCM (ILCM) aiming to promoting the detection speed. But it degrades the detection performance because of setting the moving step to 1/2 of the windows side length. In addition, Wei *et al.* [3] proposed a novel method for IR small target detection inspired by the biological visual mechanism called multiscale patch-based contrast measure (MPCM), which has the ability to simultaneously detect bright and dark targets in IR images. But it is not robust to heavy clutters [16]. Other similar methods such as weighted local difference measure [15], saliency map fusion method [17], and entropy-based window selection method [18] are all time-consuming.

Considering the above limitations of state-of-the-art methods, a novel HVS inspired small target detection method called high-boost-based multiscale LCM (HB-MLCM) is proposed in this letter. It can be roughly divided into three stages. First, improved high boost filter (IHBF) is proposed to obtain a local saliency map where the target area is enhanced and the background noises and clutters are suppressed. Then, a simple MLCM is carried out to further enhance the targets. Finally, a simple thresholding method is used to segment targets. Experimental results show that the proposed method achieves a better performance than the state-of-the-art methods with regard to detection speed, detection rate, and false alarm rate (FAR). The main contributions of this letter can be summarized as follows.

1) IHBF is designed. It can enhance the high frequency signal where the target may appear and suppress the low frequency signal simultaneously.

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2) HB-MLCM is introduced. It can enhance the true target and suppress background clutters significantly.
3) An HB-MLCM-based detection method is designed to process IR images with complex backgrounds. By applying such method on three image sequences with diverse complicated backgrounds, it demonstrates that the designed method performs well in comparison to other methods.

The remaining of this letter is organized as follows. In Section II, the proposed method would be discussed in detail. In Section III, extensive experiments are carried out to verify the effectiveness of the proposed method. Finally, we conclude this letter in Section IV.

II. Proposed Method

A. Improved High Boost Filter

In image processing, HBF is often used to enhance high frequency component while still keeping the low frequency components [19]. The HBF can be defined by

$$I_{\text{HBF}} = (1+l)I_o - l \times I_m \tag{1}$$

where I_o and I_m represent the original image and the smooth image, respectively. In (1), I_{HBF} is the result of high boost filtering when $l > 1$.

As shown in (1), HBF can sharpen the edges of IR images. However, the IR small target is often embedded in heavy background clutters. HBF can produce a lot of high responses in complex backgrounds. Consequently, it is not feasible to use HBF to enhance small targets in IR images directly. In this letter, IHBF is designed to enhance small targets in IR images. Consequently, (1) can be rewritten as

$$\hat{I}_{\text{hp}} = \max\{I_o - I_m, 0\} \tag{2}$$

$$I_{\text{IHBF}} = I_o \circ \hat{I}_{\text{hp}} \tag{3}$$

where $\circ$ denotes the Hadamard product of matrices. It is easy to find that the outputs of the smooth backgrounds would become zero in (2). That is to say, while retaining the target area, the background area would be significantly suppressed. After the processing of (3), we can have a set of candidate targets. IHBF is fast, and it is very important for practical applications.

B. High-Boost-Based Multiscale Local Contrast Measure

In real application, IR small target detection is a challenging task. IR small target images have blob-like structures. There are some prior knowledge available for target detection, for example, the interior of the target area is relatively smooth but the difference between the target and its corresponding background clutters is relatively large. Hence, this property can be used to design a method to enhance the local difference. In this letter, a small target detection method that takes full advantage of the contrast between the target and its corresponding backgrounds is designed to promote the signal–clutter ratio (SCR).

A window model shown in Fig. 1 is used to design the method, where the central region marked with a red box

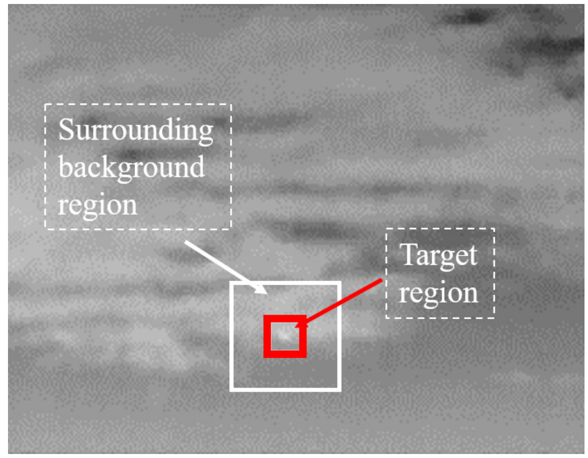


Fig. 1. Nested structure window model.

denotes the target and its surrounding area marked with a white box is the backgrounds. The local difference between the target and its corresponding surrounding backgrounds can be given by

$$d = m_T - m_B \tag{4}$$

where m_T and m_B are the mean values of the target region and its corresponding background area, respectively. And m_T and m_B can be calculated by

$$m_T = \frac{1}{N_T}\sum_{i=1}^{N_T} \upsilon_i, \qquad m_B = \frac{1}{N_B}\sum_{j=1}^{N_B} \upsilon_j \tag{5}$$

where N_T is the number of pixels in the target region and υ_i represents the gray value of ith pixel. Similarly, N_B is the number of pixels in its corresponding background region and υ_j is the gray value of jth pixel.

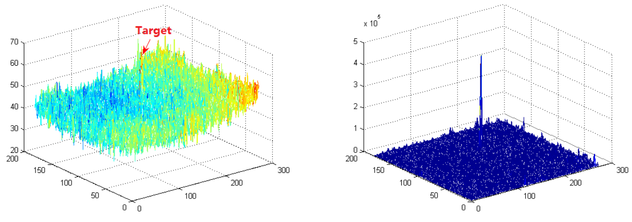
Generally, the size of small targets changes from 2×2 to 12×12 in IR images [20]. Hence, the small target could be estimated with appropriate window [3]. In order to match the real target better, the size of target region in Fig. 1 should be changed with the size of real targets. Consequently, in this letter, a set of local contrast maps would be obtained using the window model. In order to maximize the contrast between targets and its corresponding surrounding backgrounds, HB-MLCM is proposed in this letter. It can be given by

$$C = \Big(\max_{k\in\{1,2,\ldots,K\}}(|d^k|) - \min_{k\in\{1,2,\ldots,K\}}(|d^k|)\Big)^2 \tag{6}$$

$$d^k = m_T^k - m_B^k, \quad k = 1, 2, \ldots, K \tag{7}$$

where d^k denotes the local contrast of the current position in kth scale and $|d^k|$ symbolizes the absolute value of d^k. m_T^k and m_B^k represent the mean values of the target region and its corresponding background region in kth scale, respectively. In experiments, K is set to 4 and the size of target region is set to 3×3, 5×5, 7×7, and 9×9 pixels, respectively.

The HB-MLCM can also be given with Algorithm 1, where M and N are the height and width of the input image, respectively. The 3-D surf view of one original image and the corresponding output of HB-MLCM are also given in Fig. 2. It is easy to find that the target can be enhanced and the backgrounds can be suppressed significantly.



(a) (b)

Fig. 2. Sample of HB-MLCM. (a) 3-D mesh view of the original image. (b) HB-MLCM map.

Algorithm 1 High-Boost-Based Multiscale Local Contrast Measure

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Input: I_{IHBF} map
Output: HB-MLCM map

```
for i = 1 to M do
  for j = 1 to N do
    for k = 1 to K do
      d^k = m_T^k − m_B^k
    end for
    C = (max_{k∈{1,2,...,K}}(|d^k|) − min_{k∈{1,2,...,K}}(|d^k|))^2,
    Replace the current central pixel value with the obtained C.
  end for
end for
return HB-MLCM map
```

C. Proposed Detection System

In this section, we would introduce the proposed detection system. In Algorithm 1, we can obtain the HB-MLCM map of the input image. Next, we would use an adaptive threshold to segment the interested small target. The threshold T can be calculated by

$$T = \mu + \varepsilon \times \sigma \tag{8}$$

where μ and σ represent the mean and variance of the HB-MLCM map, respectively, and ε is a constant which is determined empirically. Furthermore, in order to intuitively show the proposed small target detection method, the flowchart of this detection system is shown in Fig. 3. It is easy to find that the proposed small target detection method is simple.

D. Detection Ability Analysis

From the aforementioned definition, we can find that HB-MLCM can enhance the target and suppress background clutters and noises. Noises usually appear as pixel-sized form with high brightness in IR images [12]. In contrast to this, a target concentrates in a small, homogeneous, and compact area, and its interior is relatively flat. Consequently, when the current pixel belongs to the background, we can find that

$$m_T \cong m_B \quad \text{and} \quad \max(|d^k|) \cong \min(|d^k|). \tag{9}$$

Thus

$$C \cong 0. \tag{10}$$

For a target, it could be found that

$$m_T > m_B \quad \text{and} \quad \max(|d^k|) > \min(|d^k|). \tag{11}$$

Therefore

$$C \gg 0. \tag{12}$$

We can find that the proposed HB-MLCM can enhance the target and suppress the noise simultaneously. Furthermore, the value of pixels in the final contrast map denotes the "probability" of being a target. Hence, the area with the largest value in the final contrast map is most likely to be the target. Consequently, the HB-MLCM-based small target detection method can work well for IR small target images with complex backgrounds.

III. Experimental Results

A. Experimental Setup

In order to validate the proposed method, three IR image sequences with strong noises and clutters are used in experiments (see Fig. 4), denoted as sequence 1, 2, and 3, respectively. For a comprehensive evaluation, some metrics including the running time, true positive rate (TPR), FAR, receiver operation characteristic (ROC) curve [21], and SCR gain (SCRG) [21] are used. TPR and FAR are defined by

$$\text{TPR} = \frac{\#\text{real targets detected}}{\#\text{real targets}} \times 100\% \tag{13}$$

$$\text{FAR} = \frac{\#\text{false targets detected}}{\#\text{targets detected}} \times 100\% \tag{14}$$

respectively. The ROC curve represents the relationship between the TPR and FAR. SCRG measures the ability of noise suppression and target enhancement. The top-hat [22], LCM [1], ILCM [12], and MPCM [3] are used as baseline methods to validate our target detection method. In this letter, all the experiments are conducted using MATLAB on a personal computer with 2.6-GHz i5-4210M CPU processor and 8-GB memory.

B. Experimental Results on Sequence 1

Fig. 4(a) shows that a dim and small target marked with a red box is buried in heavy clouds. And the contrast between the target and its corresponding background clutters is very low. In addition, the background clutters around the target change over time. This increases the difficulty of target detection tasks.

Sequence 1 contains 110 frames and the resolution of images is 200×256. In the experiment, the parameter ε in (8) is set to 25. Table I shows that the proposed method achieves the best results in TPR, FAR, running time, and SCRG when compared with baseline methods. MPCM achieves similar results to the proposed method in TPR and FAR. However, MPCM is more time-consuming than the proposed method. LCM also has a good performance but the detection performance is sensitive to the value of ε. In experiments, good results can be obtained by LCM only when the parameter ε in (8) belongs to [3, 3.5]. Top-hat and ILCM cannot detect the target effectively. In Fig. 5, we present the ROC curves of five methods for the three real small target image sequences. Fig. 5(a) shows that LCM, MPCM, and our proposed method can achieve better results.

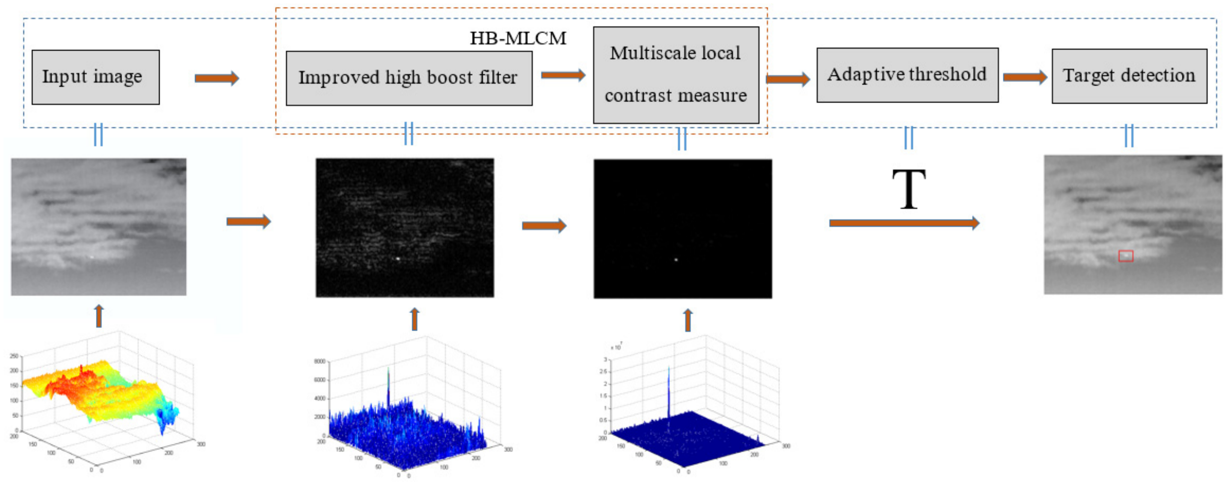
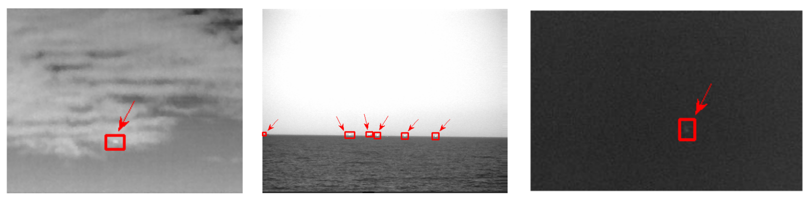
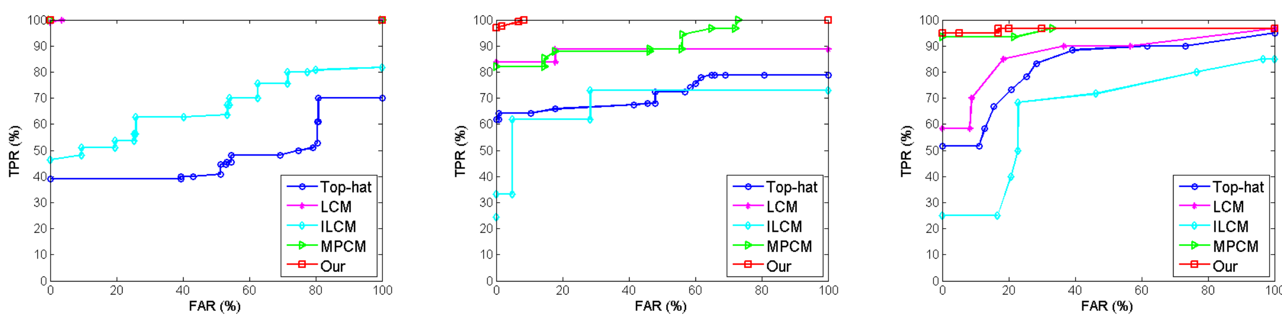


Fig. 3. Flowchart of the proposed detection system.



(a) (b) (c)

Fig. 4. Examples of the experimental image. (a) Sequence 1. (b) Sequence 2. (c) Sequence 3.



(a) (b) (c)

Fig. 5. ROC curves by different methods on three sequences. (a) ROC curve of sequence 1. (b) ROC curve of sequence 2. (c) ROC curve of sequence 3.

TABLE I

COMPARISON OF DIFFERENT METHODS ON SEQUENCE 1

Method	Top-hat	LCM	ILCM	MPCM	Our
TPR	60.91	**100.00**	80.77	**100.00**	**100.00**
FAR	80.91	3.64	80.00	**0.00**	**0.00**
SCRG	13.97	1.85	1.49	14.25	**28.47**
Time (s)	0.06	0.27	0.11	0.15	**0.06**

TABLE II

COMPARISON OF DIFFERENT METHODS ON SEQUENCE 2

Method	Top-hat	LCM	ILCM	MPCM	Our
TPR	78.86	83.74	73.00	85.37	**97.56**
FAR	65.85	17.89	28.46	17.89	**1.67**
SCRG	95.86	2.00	1.29	168.89	**299.66**
Time (s)	0.18	1.06	0.24	0.64	**0.15**

C. Experimental Results on Sequence 2

Sequence 2 is captured on the sea surface where heavy noises (sea-sky clutters) exist and the resolution of the image is 576×768. This sequence has 20 frames. From Fig. 4(b), we can find that there are six IR small targets marked with red boxes. However, the contrast between the target and its corresponding background clutters is so weak that the HVS can hardly distinguish it. Furthermore, one of the targets appears on the left boundary of the image, which makes the target detection more difficult.

Table II shows the results of all target detection methods. LCM is very sensitive to the value of ε, and it can achieve better results only when ε belongs to a small range. And this phenomenon can also be explained from SCRG of LCM. Compared with LCM, although the ILCM algorithm is faster, its performance with regard to TPR and FAR is worse than LCM. Top-hat has high FAR. The performance of the proposed method can also be verified by ROC curve given in Fig. 5(b). The ROC curve of our method is located in the

TABLE III
COMPARISON OF DIFFERENT METHODS ON SEQUENCE 3

Method	Top-hat	LCM	ILCM	MPCM	Our
TPR	90.00	90.00	71.67	93.33	**95.00**
FAR	73.33	36.67	46.29	**0.00**	**0.00**
SCRG	12.43	4.58	2.34	13.15	**25.11**
Time (s)	0.06	0.27	0.11	0.16	**0.06**

top-left corner, which means that our method achieves the best detection performance.

D. Experimental Results on Sequence 3

For sequence 3, it has 60 frames and the size of images is 180×270. Fig. 4(c) shows that this sequence has complex backgrounds and low SCR. Table III shows that the proposed method has the best performance in TPR, FAR, and detection speed. Compared with the proposed method, MPCM also performs well but it is time-consuming. Although ILCM is faster than LCM, ILCM misses the interested target [3] and it has high FAR. Top-hat is faster compared with the other target detection methods, but it has high FAR. From Fig. 5(c), the similar conclusion can also be obtained. We can find that the proposed method achieves the best performance, which implies that our method works more robustly for different target movements and backgrounds with low SCR values.

E. Discussion

From experimental results on three IR image sequences, we can find that the proposed method achieves the best result with respect to the detection speed, TPR, and FAR compared with the state-of-the-art methods. The reasons for the good performance can be summarized as follows.

1) IHBF is designed to screen out suspicious target regions. In this way, a simple contrast measure can be used to find the true targets. So the computational cost can be reduced and high accuracy can be obtained.
2) HB-MLCM is proposed for further enhancing the target and suppressing the backgrounds. In this stage, the responses of the background clutters in the previous stage can be suppressed. This operation can ensure the high TPR and low FAR of the proposed method.
3) In the proposed method, the size of the external window is fixed and it is set to 15×15 pixels in experiments. However, in [3], the size of the external window is changed with the internal window. The fixed size window contributes to the fast detection speed.

IV. CONCLUSION

This letter presents a novel method based on the human visual contrast mechanism for small IR target detection. It can take full advantage of the difference between targets and its surrounding backgrounds, to efficiently enhance small targets and suppress the backgrounds. We have carried out the performance comparison among the proposed HB-MLCM, Top-hat, LCM, ILCM, and MPCM. The experimental results on three real IR image sequences demonstrate that the proposed method can achieve high detection accuracy and is fast. It is an efficient method for the IR small target detection in the complex backgrounds. However, still it can be improved. For example, an adaptive thresholding method for target segmentation can be designed in the future.

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