We propose improved multilevel filters (IMLFs) involving the absolute value operation into the algorithmic framework of traditional multilevel filters (MLFs) to improve the robustness of infrared small target enhancement techniques under a complex infrared cluttered background. Compared with the widely used small target enhancement methods which only deal with bright targets, the proposed technique can enhance the infrared small target, whether it is bright or dark. Experimental results verify that the proposed technique is efficient and practical.

**OCIS codes:** 100.3008, 100.2000, 100.2960, 100.0100.

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If $f(i,j)$ is greater than $g(i,j)$, the subtraction result at point $(i,j)$ will remain in $s(x,y)$; otherwise, $s(i,j)$ will be set to zero.

Therefore, the bright spot, which is recognized as a potential small target, can be obtained from $s(x,y)$. The above calculative process indicates the constrained conditions of traditional MLFs and the cause of failing to enhance the dark target.

To optimize the algorithmic adaptability of traditional MLFs and enhance the potential target, whether it appears as a bright spot or a dark spot on the infrared focal plane, an absolute value operation (ABS) is introduced into the traditional algorithmic framework. Based on the improved algorithmic framework (Fig. 2), the bright or dark infrared target can be adaptively enhanced by IMLFs.

Detailed analysis of the IMLFs is shown as follows. In Refs. [4, 5], the characteristics of the background, target, and noise in the space and frequency domain are prominently different and are not influenced by the infrared signature. Thus, as long as the target’s region of interest has high local contrast, the bright or dark target can be successfully enhanced. In Fig. 2, the ABS is the successive operation of subtraction operation, and the gray intensity of $s(i,j)$ is determined by

$$s(i,j) = |f(i,j) - g(i,j)|. \quad (2)$$

Given the adoption of ABS operation, all pixels in $f(x,y)$ and $g(x,y)$ are considered in the ABS calculation, and neither pixel is removed from $s(x,y)$. Therefore, the ABS operation is guaranteed for enhancing the bright or dark target in the infrared clutter background. Although the false alarm rate may increase after ABS operation, the infrared target can be enhanced successfully.

We consider some infrared images with the size of $320 \times 240$ (pixels) obtained from the forward-looking infrared (FLIR) system to validate the performance of the proposed method for small target enhancement in an infrared cluttered background. Two images cut from the original image sequences with an appropriate size are shown in Fig. 3. The small target is a ship, labeled by a white rectangle.

The infrared small target usually has a small-sized, irregular shape; thus, the shape of the filtering mask can usually be a circle or a rectangle. The filtering mask used in this letter is a rectangle with a size of $5 \times 5$ (pixels). The mean filter is adopted to stand for all low pass filters

\[ F \rightarrow \{p_1, p_2, p_3\} \rightarrow \text{ABS} \rightarrow \{q_1, q_2\} \rightarrow q_4 \rightarrow F_{\text{out}} \]

Fig. 2. Improved multilevel filter.

Fig. 3. Typical infrared images. (a) Infrared image with a bright target; (b) infrared image with a dark target.

in Fig. 2. When the target appears as a bright spot in the infrared image, the target enhancement performance of IMLFs is almost the same as that of traditional MLFs.

Taking Fig. 4(a1) as an example, the target appears as a bright spot in the infrared cluttered background. Based on the three-dimensional (3D) plot images of gray intensity in the target region and its surrounding region (Figs. 4(b2) and (c2)), the background-suppressing performance of traditional MLFs is better than that of IMLFs. However, for all, the amplitude of the target is significantly larger than that of the background after IMLFs, which also maintains satisfactory performance of target enhancement.

Additionally, as illustrated in Fig. 5(a1), the target appears as a dark spot in the infrared clutter background. From the 3D plot images of gray intensity in the target region and its surrounding region (Figs. 5(a2) and (b2)), we know that the background clutters have not been suppressed and that the target has not been enhanced by traditional MLFs. Thus, under this condition,
Table 1. Comparison of Target Enhancement (SCR Gain)

<table>
<thead>
<tr>
<th>Method</th>
<th>Bright Target (5 x 5 (pixels))</th>
<th>Dark Target (7 x 7 (pixels))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max-Max</td>
<td>1.32751</td>
<td>0.83190</td>
</tr>
<tr>
<td>Max-Median</td>
<td>0.97746</td>
<td>1.13071</td>
</tr>
<tr>
<td>Max-Mean</td>
<td>0.86606</td>
<td>0.95150</td>
</tr>
<tr>
<td>Gaussian Filter</td>
<td>0.95153</td>
<td>0.97434</td>
</tr>
<tr>
<td>Averaging Filter</td>
<td>0.87352</td>
<td>0.95114</td>
</tr>
<tr>
<td>WTH</td>
<td>0.55783</td>
<td>0.21751</td>
</tr>
<tr>
<td>BTH</td>
<td>0.04195</td>
<td>0.84866</td>
</tr>
<tr>
<td>MLFs</td>
<td>2.19600</td>
<td>0.20012</td>
</tr>
<tr>
<td>IMLFs</td>
<td>1.98792</td>
<td>1.81456</td>
</tr>
</tbody>
</table>

The traditional MLFs fail to work or achieve an unsatisfactory performance. However, for the IMLFs, the dark infrared target can be enhanced effectively and maintain better performance of background suppression (Figs. 5(a2) and (b2)).

To further prove the improved performance of IMLFs for infrared small target enhancement, some widely used methods, such as Gaussian filter, averaging filter, max-max, max-mean, max-median, WTH, and MLFs methods are used to enhance a bright small target in images; in contrast, BTH is used to enhance a dark small target in images. The size of the filter mask in these methods is set at 5 x 5 (pixels). The metric signal-to-clutter ratio (SCR) is adopted to compare their performances, given as

$$\text{SCR} = \frac{\mu_s - \mu_b}{\sigma_b},$$  \hspace{1cm} (3)

where $\mu_s$ is the average intensity of the target, $\mu_b$ is the average intensity of pixels that belong to the neighbor area around the target, and $\sigma_b$ is the standard deviation of the neighbor pixels around the target (31 x 31 pixels). The results are shown in Table 1. Here, a largerSCR means better performance of target enhancement. Furthermore, the SCR gain is given as

$$\text{SCR gain} = \frac{\text{SCR}_{\text{out}}}{\text{SCR}_{\text{in}}},$$  \hspace{1cm} (4)

where $\text{SCR}_{\text{out}}$ is the SCR of the image after the background is suppressed, and $\text{SCR}_{\text{in}}$ is the SCR of the original image.

In Table 1, for the bright target under heavy cluttered background, the SCR gain of BTH is the lowest and traditional MLFs maintains the highest. This suggests that BTH performs the worst while MLFs is the best among all the methods. In addition, the performance of IMLFs, although not as excellent as that of traditional MLFs, is quite satisfying as indicated clearly in the illustrated figures. In terms of dark target, traditional MLFs present the least SCR gain value with WTH showing no better performance; in turn, IMLFs is considered the best in dealing with dark target. Thus, top-hat transformation (WTH or BTH) based target enhancement techniques cannot process both bright and dark targets. Moreover, although the max-max, max-mean, and max-median techniques have good performance for dark small target, the average intensity of each enhanced target is still darker than the intensity of which people could locate the target at first glance. However, after being dealt by the IMLFs, the original dark target has been transformed into a bright and discernable one. Therefore, considering the performances involving bright and dark targets comprehensively, the IMLFs stand superior to any one included in Table 1, and could guarantee a successive and automotive procedure of target enhancement and detection, regardless of the brightness of the target compared with the background.

In conclusion, We propose IMLFs to robustly enhance the bright or dark infrared small target and to improve the performance of traditional MLFs for infrared small target enhancement. Experiments verify that the IMLFs can be used for bright or dark infrared small target enhancement, and the proposed technique performs better than other widely used methods.

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References