Improved multilevel filters to enhance infrared small target

Xiaoping Wang (汪小平)[1*], Tianxu Zhang (张天序)[1], Luxin Yan (颜露新)[1],
Man Wang (王　曼)[1], and Jiawei Wu (吴家伟)[2]

[1]*Institute for Pattern Recognition and Artificial Intelligence,*
Huazhong University of Science and Technology, Wuhan 430074, China
[2]*School of Electronic Information Engineering, Beihang University, Beijing 100191, China*
[*]*Corresponding author: wxphero2008@yahoo.cn*

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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.

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Numerous techniques have been presented and widely used in the field of infrared small target enhancement and detection, which is dominated by top-hat transformation[1−3], multilevel filters (MLFs)[4,5], max-max, max-median, max-mean[6], particle filter[7], and other methods[8−12]. Although these methods can achieve good performance, they share the critical drawback of requiring the average intensity of the infrared small target (bright or dark) to be acquired beforehand. One way of improving the robustness of existing methods is by incorporating the infrared imaging characteristics to predict the average intensity of the actual target. Based on such prediction, the small target can be enhanced by the combination of some effective methods. Although these combined methods can perform well in certain cases, the accuracy of target intensity prediction is a difficult task and has a direct influence on the performance of target enhancement, which has been proven as an improper method because it fails to meet the requirement of high robustness. Another way is to determine the drawbacks of the existing methods and rearrange them according to the purpose of automatic target recognition applications. However, thus far, the improvement of existing methods is very limited and could not live up to the automation of a whole procedure of target enhancement and detection.

To distinctively improve the robustness of small target enhancement techniques, we propose an improved multilevel filters (IMLFs) proven to be efficient in the enhancement of bright small targets as well as dark ones. Experiments verify that the proposed multilevel filters perform better than traditional MLFs and other widely used methods for infrared small target.

The algorithmic framework of traditional MLFs presented by Zhang *et al.* is shown in Fig. 1[4,5]. Here, F represents the amplitude spectrum of the original image $f(x,y)$, Lp represents the amplitude spectrum of low pass filter (LPF), and Lq represents the amplitude spectrum of another LPF.

Through detailed analysis of the characteristics of the background, target, and noise in the frequency domain of the infrared image, we know that the background is dominant in low frequency, the target appears in middle frequency, and noise is clear in high frequency. These characteristics indicate that traditional MLFs use frequency difference to suppress the cluttered background and enhance the potential small target.

The small target can usually be recognized as a small bright region embedded in the infrared clutter background. Thus, the gray intensity of the surrounding regions will be clearly different from that of the target region, which also means that the local contrast of the target is higher than its surrounding objects. However, if infrared signature reduction techniques are adopted[13,14], the infrared intensity of the small target may be the lowest, indicating that the small target may appear as a dark spot on the infrared focal plane. Therefore, an IMLFs is proposed to enhance the small target, whether it is a bright spot or a dark spot, and to achieve satisfactory performance of target enhancement based on the characteristics of IMLFs.

Taking an infrared image $f(x,y)$ of M-pixels width and N-pixels height as an example, the processing procedures of traditional MLFs are expatiated as below. All mid-result images have the same image size with $f(x,y)$. The image after multilevel low pass filters from Lp_1 to Lp_n, which is denoted by $g(x,y)$, represents the low frequency information of $f(x,y)$. We let $s(x,y)$ represent the input image of low pass filters Lq_1 and $f(i,j)$, $g(i,j)$, and $s(i,j)$ denote the gray intensity at point (i,j) in $f(x,y)$, $g(x,y)$, and $s(x,y)$, respectively. Moreover, $s(x,y)$ stands for the middle and high frequency information of $f(x,y)$, and the gray intensity of $s(i,j)$ is determined by

$$s(i,j)=\begin{cases} f(i,j)-g(i,j) \ , & f(i,j)>g(i,j) \\ 0 \ , & f(i,j)\leq g(i,j). \end{cases} \quad (1)$$

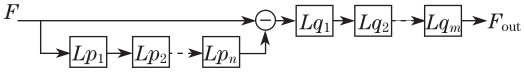

Fig. 1. Traditional multilevel filter.

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

$$s(i,j) = \left| f(i,j) - g(i,j) \right|. \tag{2}$$

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 × 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 × 5 (pixels). The mean filter is adopted to stand for all low pass filters 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.

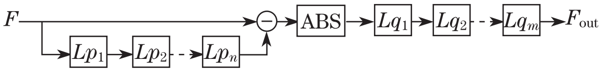

Fig. 2. Improved multilevel filter.

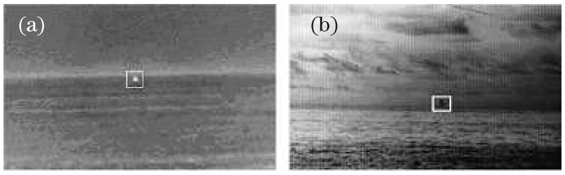

Fig. 3. Typical infrared images. (a) Infrared image with a bright target; (b) infrared image with a dark target.

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,

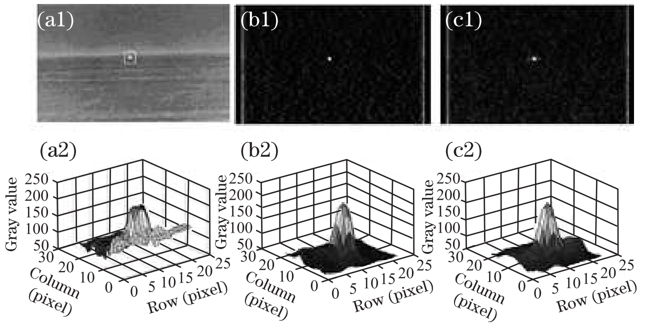

Fig. 4. Infrared small target enhancement. (a1) Original image with a bright target; (a2) 3D surface plot of the gray intensity of the target region and the surrounding region in (a1); (b1) result image after traditional MLFs; (b2) 3D surface plot of the gray intensity of the target region and the surrounding region after traditional MLFs in (b1); (c1) result image after IMLFs; and (c2) 3D surface plot of the gray intensity of the target region and the surrounding region after IMLFs in (c1).

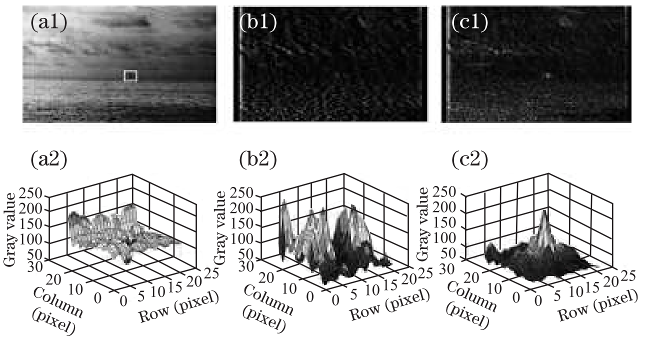

Fig. 5. Infrared small target enhancement. (a1) Original image with a dark target; (a2) 3D surface plot of the gray intensity of the target region and the surrounding region in (a1); (b1) result image after traditional MLFs; (b2) 3D surface plot of the gray intensity of the target region and the surrounding region after traditional MLFs in (b1); (c1) result image after IMLFs; and (c2) 3D surface plot of the gray intensity of the target region and the surrounding region after IMLFs in (c1).

Table 1. Comparison of Target Enhancement (SCR Gain)

	Bright Target (5 × 5 (pixels))	Dark Target (7 × 7 (pixels))
Max-Max (5 × 5 (pixels))	1.32751	0.83190
Max-Median (5 × 5 (pixels))	0.97746	1.13071
Max-Mean (5 × 5 (pixels))	0.86606	0.95150
Gaussian Filter	0.95153	0.97434
Averaging Filter (5 × 5 (pixels))	0.87352	0.95114
WTH	0.55783	0.21751
BTH	0.04195	0.84866
MLFs	2.19600	0.20012
IMLFs	1.98792	1.81456

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[6], white top-hat transformation (WTH)[1,2], black top-hat transformation (BTH)[1,2], and MLFs[4,5], are applied on the images. The 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 × 5 (pixels). The metric signal-to-clutter ratio (SCR) is adopted to compare their performances, given as

$$\mathrm{SCR} = \frac{|\mu_\mathrm{s} - \mu_\mathrm{b}|}{\sigma_\mathrm{b}}, \tag{3}$$

where μ_s is the average intensity of the target, μ_b is the average intensity of pixels that belong to the neighbor area around the target, and σ_b is the standard deviation of the neighbor pixels around the target (31 × 31 (pixels)). The results are shown in Table 1. Here, a larger SCR means better performance of target enhancement. Furthermore, the SCR gain is given as

$$\mathrm{SCR\ gain} = \frac{\mathrm{SCR}_\mathrm{out}}{\mathrm{SCR}_\mathrm{in}}, \tag{4}$$

where $\mathrm{SCR}_\mathrm{out}$ is the SCR of the image after the background is suppressed, and SCR_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

1. X. Bai, F. Zhou, and Y. Xie, J. Electron. Imag. **17,** 030501 (2008).
2. X. Bai and F. Zhou, Signal Process. **90,** 2999 (2010).
3. M. Zeng, J. Li, and Z. Peng, Infrared Phys. Tech. **48,** 67 (2006).
4. Y.-S. Moon, T. X. Zhang, Z. R. Zuo, and Z. Zuo, Int. J. Pattern Recogn. Artif. Intell. **14,** 907 (2001).
5. Z. Zuo and T. Zhang, Proc. SPIE **3545,** 372 (1998).
6. S. D. Deshpande, M. H. Er, V. Ronda, and P. Chan, Proc. SPIE **3809,** 74 (1999).
7. F. Wang, E. Liu, J. Yang, S. Yu, and Y. Zhou, Chin. Opt. Lett. **7,** 576 (2009).
8. Ch.-Q. Gao, J.-W. Tian, and P. Wang, Electron. Lett. **44,** 1349 (2008).
9. L. Yang, J. Yang, and K. Yang, Electron. Lett. **40,** 1803 (2004).
10. R. M. Liu, L. Yang, E. Liu, and J. Yang, Optical Eng. **46,** 046402 (2007).
11. B. Zhang, T. Zhang, Z. Cao, and K. Zhang, Opt. Eng. **46,** 106401 (2007).
12. H. Deng, J. Liu, and Z. Chen, Chin. Opt. Lett. **8,** 24 (2010).
13. F. P. Neele and W. de Jong, Proc. SPIE **4718,** 156 (2002).
14. H. M. A. Schleijpen and F. P. Neele, Proc. SPIE **5431,** 66 (2004).