Infrared small target enhancement by using sequential top-hat filters

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ABSTRACT

Generally in the infrared images, the targets have low contrast with the background, which makes the detection of the small targets difficult. To improve the detectability of the infrared small targets, this paper presents a novel algorithm for infrared small target enhancement by using sequential top-hat filters. Moreover, the proposed algorithm has been compared with several existing algorithms. The experimental results indicate that sequential top-hat filters could well enhance the infrared small targets and effectively suppress the background clutters.

Keywords: Detection of the infrared small targets; Infrared small target enhancement; Sequential top-hat filters

1. INTRODUCTION

Infrared small target detection is very crucial for the military searching and tracking [1]. Generally the infrared images have the characteristic of low contrast and also serious background clutters [1-3], which makes the detectability of the infrared small targets difficult. To improve the detectability of the small targets, the infrared images must be enhanced. In recent years, several enhancement algorithms have been presented to enhance the infrared images, such as mean subtraction filter [4], median subtraction filter [5], max-mean filter [6], max-median filter [6] and top-hat filter [7], etc. However, these algorithms usually could not enhance the targets very well.

In this paper, we modify the top-hat filter and present the sequential top-hat filters to enhance the infrared small targets. Moreover, experimental results verify that the sequential top-hat filters could effectively enhance the infrared targets, and its performance is better than other algorithms.

2. PROPOSED ALGORITHM

Top-hat filter has been widely applied in the detection and enhancement of infrared small target [8]. However, the infrared images usually are in low contrast and also have background clutters. So the classical top-hat filter may not well enhance the infrared small targets, which may lead to losing the target or increasing the false alarm [9, 10]. To improve the performance of the top-hat filter for infrared small target enhancement, we present the sequential top-hat filters for the infrared small targets enhancement in this section.

2.1 Top-hat filter

Dilation and erosion are two basic morphological operations [8]. Given a gray-scale image f and the structuring element B, the dilation and erosion operations of $f(x,y)$ by $B(u,v)$ can be defined as [11]

$$(f \oplus B)(x,y) = \max_{(u,v)}\left(f(x-u, y-v) + B(u,v)\right), \tag{1}$$

$$(f \Theta B)(x,y) = \min_{(u,v)}\left(f(x+u, y+v) - B(u,v)\right), \tag{2}$$

where $\oplus$ and Θ are the dilation and erosion operators, respectively.

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Then based on the dilation and erosion operations, the opening and closing operations can be defined as follows [11].

$$(f \circ B)(x,y) = (f \Theta B) \oplus B, \tag{3}$$

$$(f \bullet B)(x,y) = (f \oplus B) \Theta B, \tag{4}$$

where $\circ$ and $\bullet$ are the opening and closing operators, respectively.

According to the definitions of opening and closing operations, we can learn that the opening operation deletes the small bright regions, and the closing operation fills the small dark regions. Then, white top-hat (*WTH*) and black top-hat (*BTH*) filters are defined as [11]

$$WTH(x,y) = f(x,y) - (f \circ B)(x,y), \tag{5}$$

$$BTH(x,y) = (f \bullet B)(x,y) - f(x,y). \tag{6}$$

The small white regions could be standing out in the enhanced image by using *WTH* filter, while the small dark regions could be obviously shown in the enhanced image by using *BTH* filter. Generally, the small targets in the infrared images appear to be brighter than its surrounding regions. Therefore, the *WTH* filter could be applied to enhance and detect the infrared small targets. However, the real world infrared images are usually very complex and have serious background clutters. Thereby, the *WTH* filter usually could not enhance the infrared image very well. And in the remainder of this paper, the top-hat filter is referred as the *WTH* filter.

2.2 Sequential top-hat filters

To improve the performance of the top-hat filter for infrared small target enhancement, we present the sequential top-hat filters to enhance the infrared small targets. The sequential top-hat filters are composed of a sequence of top-hat filters with a disk structuring element of decreasing radius. Moreover, to more effectively suppress the background clutters, we modify the top-hat filter by subtracting a small value Δ from the result of top-hat filter. And, we rewrite the top-hat filter as the following expression.

$$WTH(x,y) = f(x,y) - (f \circ B)(x,y) \text{-} \Delta, \tag{7}$$

where Δ is a small value, used to suppress the background clutters of the infrared image.

And the sequential top-hat filters can be expressed as the following format.

$$\begin{cases} WTH_0(x,y) = f(x,y), \\ WTH_1(x,y) = WTH_0(x,y) - (WTH_0 \circ B_1)(x,y) \text{-} \Delta, \\ \qquad\qquad \vdots \\ WTH_n(x,y) = WTH_{n-1}(x,y) - (WTH_{n-1} \circ B_n)(x,y) \text{-} \Delta, \end{cases} \tag{8}$$

where $\{WTH_i, i = 1 \cdots n\}$ are the sequential top-hat filters, and are the corresponding structuring elements of decreasing radius.

In this paper, all the structuring elements used are flat, and the size of the structuring element should be larger than the small targets. And, the specific parameters used are set as follows: *n* is equal to 3, the decreasing step of the radius of SE is equal to 2, and Δ is equal to 10.

Fig. 1 shows a demonstration example. (a) is the infrared source image, (b)-(d) are the enhanced images by using three sequential top-hat filters, respectively. From the enhanced images, we can see that the sea clutters are gradually eliminated by the three sequential top-hat filters. From (d), it can be seen that the ship targets have been well enhanced and the background clutters have been effectively suppressed.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

To show the effectiveness of the proposed algorithm, we compared our algorithm with several existing algorithms, including mean subtraction filter [4], subtraction median filter [5] and top-hat filter [7]. Since top-hat filter has been widely applied in small target enhancement and detection, which is simple and efficient. And, mean subtraction filter and median subtraction filter are two commonly used algorithms and they are very effective for infrared small target enhancement. So, the comparison of these algorithms is reasonable. Moreover, experiments have been performed on different images. Here, two comparison examples are given, as shown in Fig. 2 and Fig. 3.

Fig. 2 and Fig. 3 show two comparison examples of infrared small ship target enhancement. From the experimental results, we can see that there are still serious sea clutters existed in the enhanced images by top-hat filter (b), mean subtraction filter (c) and median subtraction filter (d). From the enhanced images (e) of the proposed algorithm, it can be seen that the infrared ship targets are well enhanced and the sea clutters are effectively suppressed. Overall, experimental results show that our algorithm yields the best results.

4. CONCLUSIONS

This paper presents an effective algorithm for the infrared small target enhancement by adopting sequential top-hat filters. The proposed algorithm is simple and efficient. Moreover, our algorithm is compared with several existing algorithms. And, the experimental results indicate that the proposed algorithm outperforms other algorithms. Thus, the sequential top-hat filters could well enhance the infrared small targets and could effectively suppress the background clutters, which is very crucial for further target detection.

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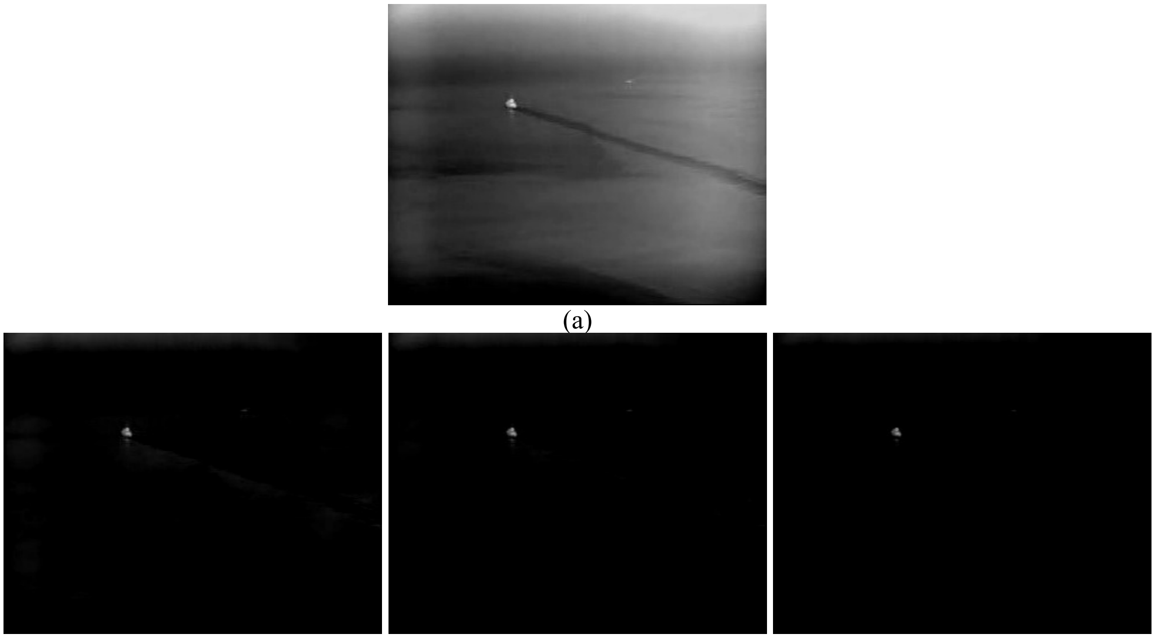
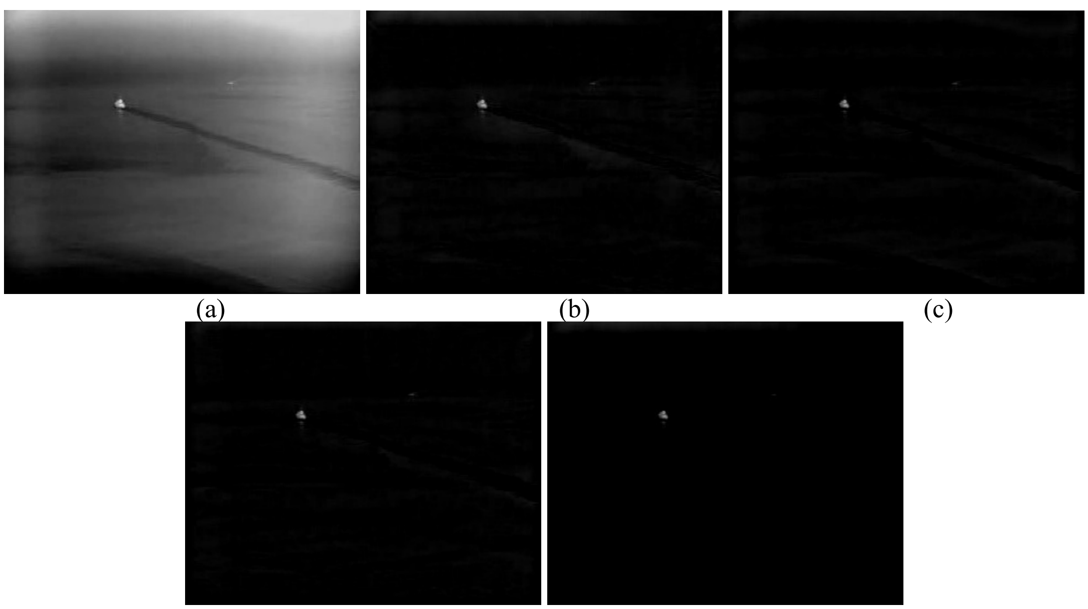


(a)

(b) (c) (d)

Figure 1. A demonstration of the proposed algorithm. (a) the infrared source image; (b)-(d) the enhanced results by three sequential top-hat filters.



(a) (b) (c)

(d) (e)

Figure 2. Comparison example 1. (a) The infrared source image. (b)-(e) the enhanced images of top-hat filter, mean subtraction filter, median subtraction filter and the proposed algorithm, respectively.

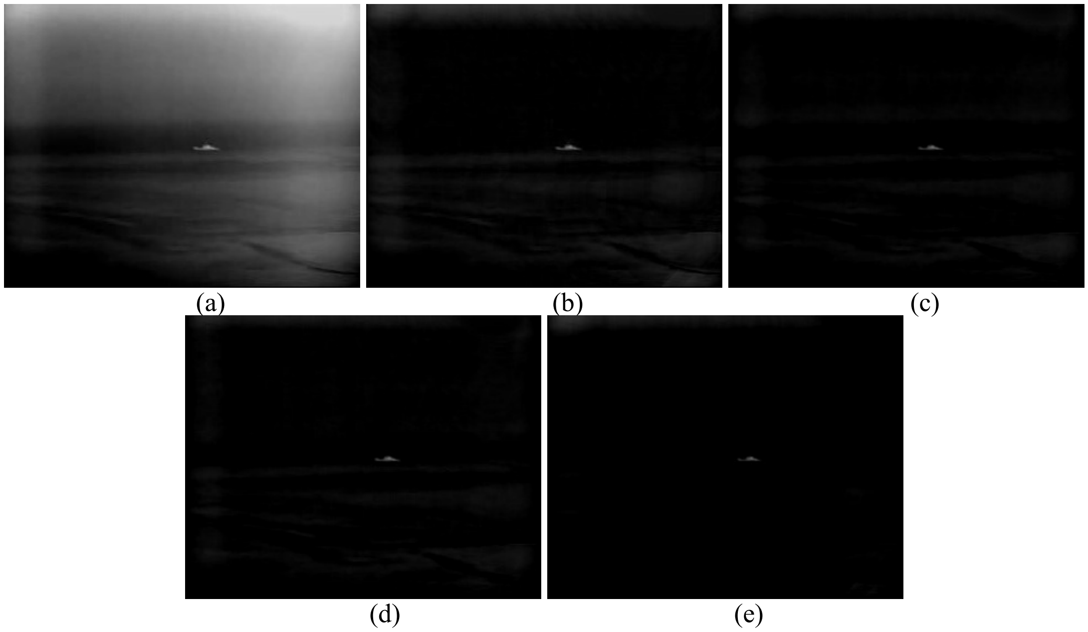


Figure 3. Comparison example 2. (a) The infrared source image. (b)-(e) the enhanced images of top-hat filter, mean subtraction filter, median subtraction filter and the proposed algorithm, respectively.