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A METHODOLOGY FOR MARINE POINT TARGET DETECTION WITH GRADIENT-BASED BACKGROUND SUPPRESSION MECHANISM

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Abstract. *The key obstacle for marine search and rescue is small target detection which can be attributed to the field of image processing. As classical top-hat has inherent advantages and disadvantages for small targets detection, one method of gradient-based top-hat operator is presented. The new top-hat operator can fully take the merits of background and its gradient information in element structure which can restrain heavy background clutter. In addition, shifting directions of gradient are utilized to help discriminate noises from the potential targets. Experiments result shows that the proposed method attains satisfying detection performance.*

Keywords: Point target detection, Background suppression, Gradient top-hat operator, Marine search and rescue

1. Introduction.

Ocean has intimate links with human beings' activities, such as global trade, and marine tourism. At the same time, human beings are experiencing sharp concern over marine security, especially for marine search and rescue process after sea accidents, which involves both factitious behavior and non-artificial factors. One of the upshots for such concern is to progress human abilities in marine search and rescue. As ocean covers huge amount of areas on the earth, it is not easy to hunt for certain targets, especially under some terrible marine conditions.

With development of modern IT technologies, computer vision and other relevant techniques have been employed to implement process of marine search and rescue (SAR). However, point target detection is crucial in marine search and rescue process, remaining a challenge for SAR. Detection for point target can mainly be divided into the following categories. The first category is the detection based on infrared technology. Targets in infrared images show higher intensity in comparison with background, which makes target perception easier. Ye and Peng employed morphology top-hat filter and energy based infrared target detection mechanism for small target detection [1]. Bai et al. did several studies in point target detection with infrared images and videos based on top-hat operator and its derivatives [2-6]. Wang and Xin employed top-hat operator to suppress background and noises [7]. Then combination of genetic algorithm and particle filter was introduced for marine target tracking.

The second category is radar-based small target detection. Wang studied track before detected (TBD) algorithm based on radar signals for point target detection [8]. Lu did the similar research as Wang [9]. Lu proposed several algorithms to track small targets in the circumstance of dynamic system. Visible-lights-aided methods are the third class for small target recognition and detection. Ren et al. provided many measurements to solve small targets detection in complicated marine circumstances, mainly concerned with visible lights [10-13]. Hsieh proposed a novel approach to the detection of small objects with low contrast [14]. Wang and Chen proposed a method to support real-time remote ship detection without extra information about ships and background [15].

Both radar and infrared-based technologies are not suitable for maritime SAR. Under maritime accidents, people to-be-rescued are easily submerged by waves or ship wake. People can be mistaken as clutters in our radar and infrared search system which challenges robustness of marine detection algorithm. Hence, visible-light based techniques are preferred in maritime SAR field. Although many researches have been done based on visible light, less attention was paid to marine target detection with the help of water waves. Concretely, intensity variation between sea surface is insignificant while variation between sea surface and maritime targets is significant. In other words, gradient between wake and its neighboring maritime targets will change greatly. So we proposed gradient-based top-hat operator for marine small target detection. The method is going to make use of gradient information to suppress background disturbance and segment small targets from noises.

2. Details of Marine Point Target Detection.

2.1. Necessity of background suppression.

Generally speaking, a to-be-detected marine image usually involves three segments: marine targets, noises and background. In fact, background occupies a large scale of the image in the way of pixels. Therefore, the mathematical expression for an image can be presented as follows [16,17]:

$$f(r,t) = f_{st}(r,t) + f_b(r,t) + f_n(r,t) \tag{1}$$

$$f_{st}(r,t) = \sum_{i=1}^{r} \partial \exp\left\{-\frac{1}{2}\left[\left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_y}\right)^2\right]\right\} \tag{2}$$

In Equation (1), $f(r,t)$ denotes a single image whose serial number is r from a series of frames, at moment t, in terms of pixels. For the right side of the equation, $f_{st}(r,t)$ indicates total pixels of small targets in the very image of $f(r,t)$, and $f_b(r,t)$ and $f_n(r,t)$ represent background and noises pixels as well. As small targets may be immersed by heavy background and noises, the mathematic form of small target resembles 2D Gaussian point-like function, so that small target can be modeled in Equation (2), where ∂ depicts the small target amplitude of its intensity, x and y are the horizontal and vertical coordinates respectively, while σ_x and σ_y represent the corresponding intensity extent parameters as well.

What is more, background takes up the majority space with the least effect for recognizing small targets which is exhibited in Figure 1 clearly. The subplot a in Figure 1 is the background-only image and subplot b is the image of its intensity distribution which shows intensity mainly concentrates on the range from 110 to 165 approximately. However, the subplot d is the intensity image with many targets which manifests image intensity varies from 89 to 190 roughly, and its vertical coordinate shows the number in different intensities, declaring small targets and noises holding less proportion in comparison with background. In a word, background is inherent in small target images which influences the detection rate tremendously.

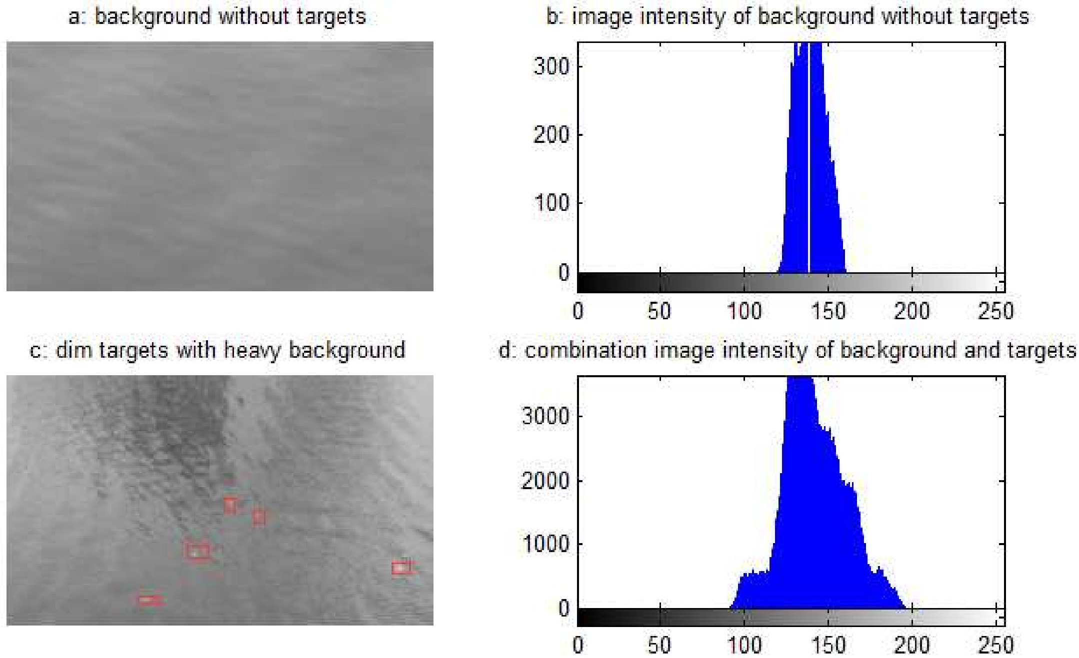


Figure 1. Small targets in marine circumstance and corresponding image intensities

2.2. Gradient-based background suppression top-hat operator.

2.2.1. *Classical morphology methods.* Morphology theory is very important and useful in the field of image processing, pattern recognition and other related fields [18,19]. The most basic operation in morphology theory is dilation and erosion with notations of $\oplus$ and $\ominus$. For the process of image dilation and erosion, they can be presented in Equations (3) and (4):

$$f \oplus b = \left\{ z \middle| \left(\hat{b}_z\right) \cap f \neq \varnothing \right\} \tag{3}$$

$$f \ominus b = \left\{ z \middle| b_z \cap f^c \neq \varnothing \right\} \tag{4}$$

$$\hat{f} = \{w | w = -t, t \in b\} \tag{5}$$

In Equation (3), f is the image to be processed with structure element b. The parameter of $\hat{b}_z$ means the reflection of B and its formula is shown in (3), while f^c in (4) is called complement of f. $\hat{f}$ is the reflection of f and each element, w, of $\hat{f}$ is obtained by Equation (5). With the help of basic morphology operations, derivative morphological operators such as opening and closing can be expressed in Equations (6) and (7) where f represents the image and b represents structure element as well:

$$f \circ b = (f \ominus b) \oplus b \tag{6}$$

$$f \cdot b = (f \oplus b) \ominus b \tag{7}$$

Operators of opening and closing can distinguish bright and dark objects respectively. And one of the common operators for gray image processing in morphology theory is top-hat operator with expressions as follows, divided into categories of white top-hat (T_{wth}) and black top-hat (T_{bth}) transformation:

$$T_{wth}(f) = f - (f \circ b) \tag{8}$$

$$T_{bth}(f) = (f \cdot b) - f \tag{9}$$

$T_{wth}(f)$ signifies operator of white top-hat and $T_{bth}(f)$ of black top-hat transformation where f is the to-be-processed image and b is the structure element. With the advantages of opening and closing operators, $T_{wth}(f)$ and $T_{bth}(f)$ can discriminate high-intensity and gloom objects readily.

However, there exist some demerits in traditional top-hat operator for image processing. Firstly, traditional top-hat transformation employs some unaltered structure elements to deal with image process which lacks in adjusting characteristics for different image patterns. Secondly, for the field of small targets detection, difference and relation between background, noises and small targets should be found effective and maximized which are not shown in traditional top-hat transformation. What is more, robustness of conventional top-hat transform should be enhanced. According to research findings, small targets are overwhelmed by heavy clutter and background, which would lead to high false alarm and detecting rate without reinforcement of classic top-hat transformation.

2.2.2. *Improved top-hat transformation with gradient change mechanism.* As the disadvantages of top-hat have been discussed aforementioned, features of background and small targets need to be imported to improve the very method's performance. Factually, background intensity varies smoothly in target-non-existence image which is shown in Figure 2. Intensity has experienced sharp change with the compound of targets, background and noises displayed in Figure 3. To make full use of such information, a radical gradient

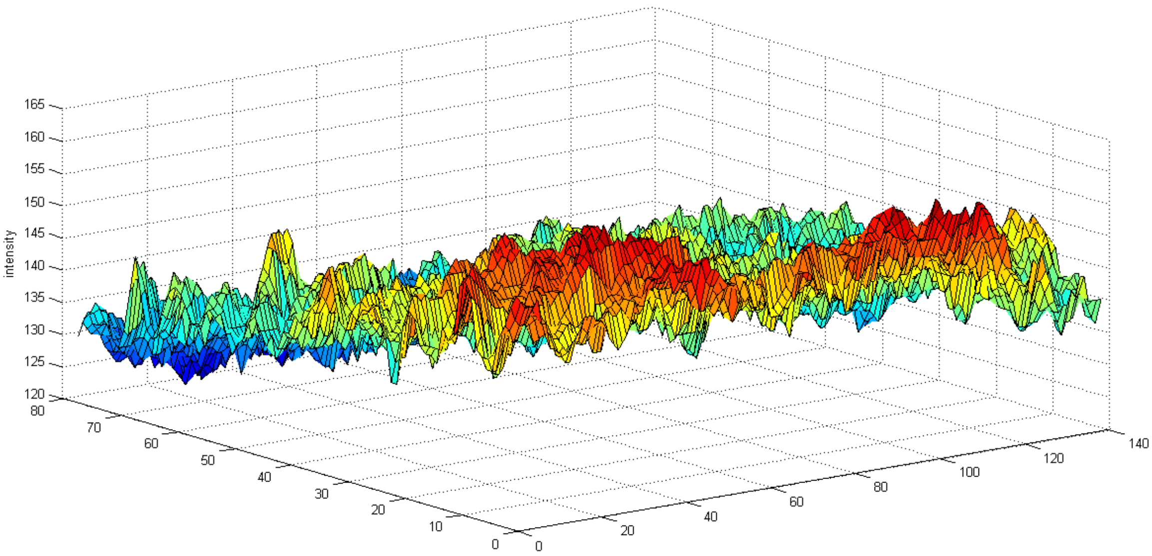


FIGURE 2. Image of background intensity in 3D view

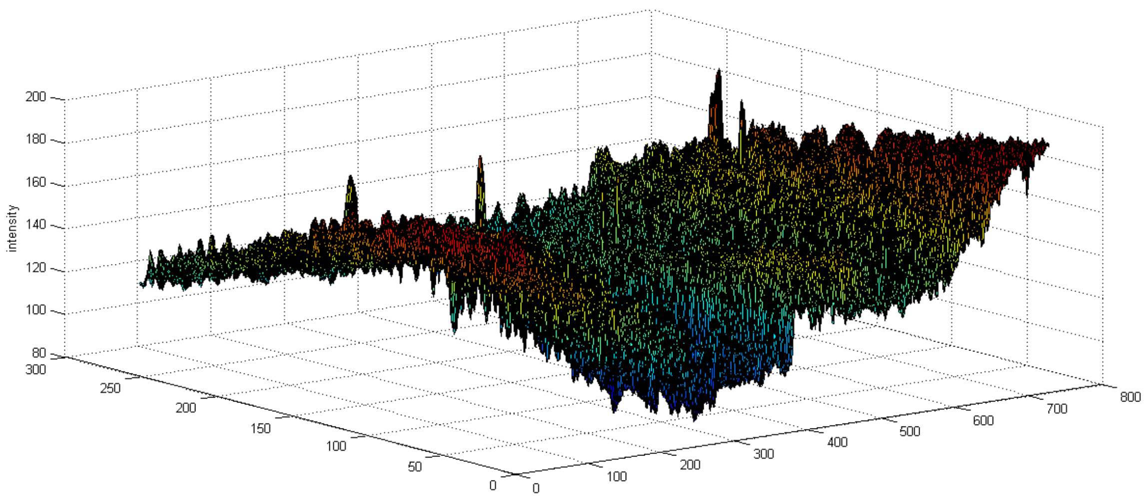


FIGURE 3. Image of multi-targets' intensity in 3D view

change mechanism merging with top-hat operator is introduced.

$$NT_{wthBackground}(f) = f - (f_{bg} \circ B_{ng}) \tag{10}$$

$$NT_{bthBackground}(f) = (f_{bg} \cdot B_{ng}) - f \tag{11}$$

$$NT_{wthTarget}(f) = f - (f_{target} \circ B_{ng}) \tag{12}$$

$$NT_{bthTarget}(f) = (f_{target} \cdot B_{ng}) - f \tag{13}$$

For Equations (10) to (15), f is the image to be analyzed, f_{bg} represents pixel set of background in the image f and hereinafter it can be written as $f_{background}$. Similarly, f_{target} is pixel set of possible small targets in the image f and it is referred to as $f_{smalltarget}$ as well.

B_{ng} is a new element structure which consists of background, target and image gradient information which means different equations with different expressions. The parameter B_{ng} for background top-hat operator in (10) and (11) can be presented as follows:

$$B_{ng} = f_{background} \nabla g \tag{14}$$

while B_{ng} for small target top-hat operator in (12) and (13) can be expressed in (15):

$$B_{ng} = f_{smalltarget} \nabla g' \tag{15}$$

Equations (10) and (12) are called modified-white-top-hat (MWTH) while Equations (11) and (13) are called modified-black-top-hat (MBTH). Both of these equations are analogous to the classical white and black top-hat and they are aiming for target suppressing and small target detection. Hence, background-suppression and target detection of MWTH are elaborated in detail and counterpart of MWTH can be reasoned by that analogy. The result of Equations (10) and (12) can be expanded into the following equations:

$$\begin{aligned} NT_{wthBackground}(f) &= f - (f_{bg} \circ B_{ng}) \\ &= f - \left[f_{background} \circ \left(f'_{background} \nabla g\right)\right] = f_{noise} + f_{target} \end{aligned} \tag{16}$$

$$NT_{wthTarget}(f) = f - (f_{target} \circ B_{ng}) = f - \left[f_{target} \circ \left(f'_{target} \nabla g'\right)\right] = f_{noise} + f_{background} \tag{17}$$

First, let $NTB_{derived} = f_{noise} + f_{target}$ and $NTT_{derived} = f_{noise} + f_{background}$. Equations (16) and (17) show a clear vision that their common element is image's noise which can be ruled out by subtraction operator. So the final expression for target and background can be described as:

$$f_{noise} = NTB_{derived} \cap NTT_{derived} \tag{18}$$

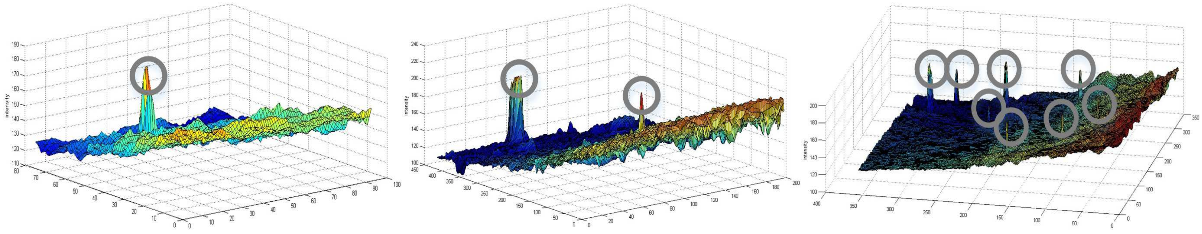
$$f_{target} = NTB_{derived} - f_{noise} \tag{19}$$

$$f_{background} = NTT_{derived} - f_{noise} \tag{20}$$

With such definitions and operators, the advantages of top-hat operator are explored profoundly and disadvantages are hampered abundantly. The above definitions indicate some fresh features different from classical top-hat operator.

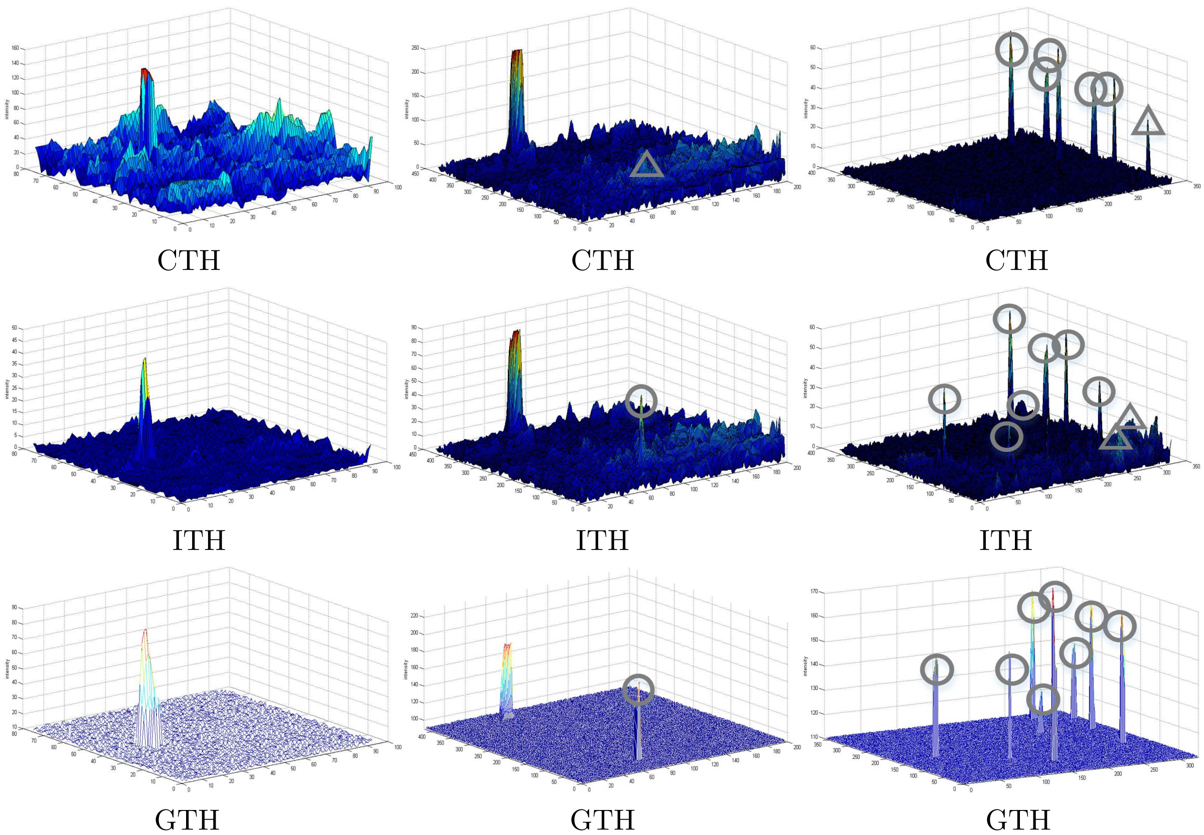
3. **Experiments and Analysis.** Marine SAR is practical application environment for the top-hat operators as characteristics of excellent small targets detection. All the experiments are carried out on the small targets images with sea-background. For the sake of acquiring integrated performance, different top-hat operators are employed which include classical top-hat (CTH) operator [19], improved top-hat (ITH) [2] and gradient involved top-hat (GTH) proposed in this paper. We implemented the three detection models on Win 7 Operation System, 6GB RAM with CPU of 2.9 GHz. All models were fulfilled by Matlab (R2011 version).

Figure 4 is the original collected image shown in the form of three dimensional gray intensities. According to subplot (a) in Figure 4, images with one small target turn out less noises and interference and subplot (a) of Figure 5 is the performance comparison result by different methods. Three sub-graphs in Figure 5 are intensity distributions of CTH,



(a) Single target (b) Two targets (c) Multiple targets

FIGURE 4. Gray intensity graphs for different targets



(a) (b) (c)

FIGURE 5. Performance of different top-hat operators on different targets: (a) detection performance for single target; (b) detection performance for two targets; (c) detection performance for multiple targets

ITH and GTH vertically. In comparison with corresponding original image in Figure 4, the first sub-picture shows that CTH may take small target as useless information because intensity amplitude of CTH detected target was lower than original target intensity in Figure 4. What is more, background of the image has not been suppressed efficiently by CTH. On the contrary, the image background has been strengthened as multiple peak values exhibited in the top image of subplot (a) in Figure 5. One possible reason for the phenomenon can be attributed to constructing element structure without background information.

ITH achieves better performance than CTH because of ITH's morphological center and anti-center operation. As shown in Figure 5, the CTH operator has some local noises which degrades the algorithm's detection accuracy. The last image of subplot (a) in Figure 5 is the detection result of GTH. As gradient of background information and the absolute value of background are comprised to build element structure, background suppression of GTH attains better performance than CTH and ITH, which brings about the target's area distinguished. The subplot (b) of Figure 4 is the initial 3D gray image, for two targets, which has heavier background clutter in comparison to the single-target sub-image. Subplot (b) of Figure 5 is the final performance evaluation in different top-hat operators for two targets detection.

As the test image has stronger background interference, the disadvantage of CTH operator has been revealed. One of the small targets is flooded by background, encircled by triangle in the first sub-graph of subplot (b) from Figure 5, which is hardly detected by CTH. Second sub-graph of subplot (b) from Figure 5 is ITH detection result which marks the small targets correctly as the second target-area is labeled by circle. However, the sub-plot demonstrates that dim targets have not been enhanced marginally as contrast between background and targets area is not so obvious.

The third image in subplot (b) of Figure 5 is the process result of GTH. With the help of background information, clutters of weak-target image are cut back resentfully which can be seen from contrast of flat area and peak-value area. The second faint target area is enhanced in the way of clipping image background efficiently. Compared with its counterparts in subplot (b) in Figure 5, the GTH gains better dim target detection performance with the help of target-gradient element structure for target reinforcement.

Disparity of small targets between different top-hat operators can be seen in subplot (c) of Figure 5. The initial image with multi-targets has eight dim targets actually. The first sub-image has detected six targets including one fake object highlighted in triangle. Part of the reason for the phenomenon is that noise of the image has higher intensity and the classical top-hat cannot rule out the noise effectively. The second sub-image is the result of ITH and it lost one small target. However, two false targets have been detected by ITH. As clearly labelled by circles shown in the last subplot in Figure 5, the proposed GTH algorithm does not lose small targets under such heavy clutter circumstance.

The GTH has shown satisfying results in ruling out background interference as intensity difference between background and targets is significant. Detection results of the third row in Figure 5 verify the above analysis. For single target detection, GTH does not demonstrate notable result as background intensity differs greatly from targets. However, test scenarios for two and multiple targets detection introduce strong background disturbance. Considering clutter background is isomorphic in gradient variation, detection model of GTH can separate background from targets area.

4. **Conclusion.** Faint targets detection is important in the field of marine search and rescue. Top-hat operator is one of the classical and common methods for dim target detection. However, classical top-hat possesses drawbacks of background suppression incompletely and inferior robustness. To solve the problem, an improved top-hat operator was proposed which constructed the element structure taking variation of background intensity into consideration. What is more, the gradient information is introduced as well which assists element structure to eliminate noises from real targets. Experiment results which are implemented with marine images show the suggested method can identify small targets from heavy background and noises. For the further research, more efforts will be paid to exploring human features for marine SAR combined with the proposed method.

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