A Method for Automatic Infrared Point Target Detection in a Sea Background Based on Morphology and Wavelet Transform

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ABSTRACT
A method is developed for the detection and segmentation of spot targets at sea surface. Firstly, the Sea-Sky-Division-Line (SSDL), close to the horizon, is detected by wavelet-transform to mark out the Target Potential Region (TPR), which can reduce the target searching range. A Row average grayscale subtraction (RAGS) operation is employed to correct the blur caused by the non-linearity distribution of the temperature field. To repress the clutter in the background and increase the SNR of the image, a morphology Top-Hat filter is utilized. Then, the image is opening by selecting a proper structuring element to acquire a few potential target points. Through searching the maximal intensity and determining a threshold, most of the false alarms can be eliminated and the doubtful targets can be segmented. When the SSDL is visible, the real point-target can be retained according to the TPR and the false target can be discarded. Under the conditions of invisibility of SSDL for it is outside of the image or it is obscure due to the weather, the segmented target is the real target. The experiment results show that the method can effectively detect and segment infrared point target in complex sea background.

Keywords: infrared point-target, wavelet transform, morphology, target detection and segmentation, sea background

1. INTRODUCTION
In the case of long distance, the initial target in the view scene is generally a small blurred bright point or spot in infrared image, called point target. Infrared receiver takes in low intensity of the target, while the noise and clutter in the background are stronger, which results in a low Signal Noise Ratio (SNR) image. On the other hand, the targets do not form clear edge contours and structure features. So the useful information is only the point shape, grayscale and motion parameters. Therefore, the detection and identification of infrared point targets in low-resolution images is an important and difficult problem in Automatic Target Recognition (ATR).

In a complex sea and sky background, the environment has great impact on the observability of targets. It is difficult to distinguish the target from the background because of the clutter caused by the sea-surface. One problem is the variability in background clutter due to the changes of reflection of the sun and sky, changing appearance of waves with distance, and variation of contrast\(^1\). Especially, when the reflection of waves and clouds is generated under violent sunniness, the intensity of many waves crest are comparative, even higher than that of the spot targets in images, which makes it difficult to separate the point-targets flooded in clutter. In this case, the common methods, such as spatial and temporal filtering or fixed grayscale threshold segmentation\(^2\), are incapable of distinguishing the point-targets from wave reflection. In real situation, there are lots of unpredictable factors, say the motion of camera and the unfixed status of
target, so various detection algorithms, such as Hough transformation, matching filter, dynamic planning, hypothesis testing and image flow, etc., based on the prediction and hypothesis motion information and noise, are inefficient on the detection of point targets in a sea surface. The SNR and the standard deviation of the background changing with wave height, distance and the position of the sun. As a result, the temporal behavior is not suitable for distinguishing the different objects from the sea background unless the behavior as a function of the many parameters be known and the parameters (such as orientation, wave-height, and object characteristics) be determined.

The algorithm proposed in this paper does not need much prior knowledge or hypotheses and specific analysis to the image features. On the base of the wavelet transform, we extract the approximation of decomposition, detect the horizontal edge, obtain the SSDL and delimit the TPR. Then, the algorithm is presented for the pre-process based on the Row Average Grayscale Subtraction (RAGS) and the morphology Top-Hat filtering in the TPR, which can effectively restrain the clutter of the waves and clouds, enhance and maintain the point-target. Finally, by choosing proper structuring elements, the opening operator is used to rule out the most false alarm points, and a few potential small targets can be obtained, searching the maximum intensity and deciding the threshold, the real target can be segmented.

2. WAVELET TRANSFORM THEORY

A wavelet is a vibrational waveform with zero average value and limited duration. As the Fourier analysis consists of signal decomposed into sine waves of various frequencies, wavelet analysis is the decomposition of a signal into shifted and scaled versions of an original wavelet called mother wavelet. When comparing wavelets with sine waves, it is intuitive that signals with abrupt changes, as it occurs for instance in object edges, are better analyzed with irregular shape wavelets than with sinusoids. Local features can also be described with wavelets, which have local extent.

In the Fast Wavelet Transform (FWT), the wavelet coefficients are calculated at dyadic scale and positions. Mallat described an example of the FWT using digital filters. This technique starts by applying a low-pass filter and a high-pass filter to the input signal. In this context, the output from the low-pass filter is called Approximation, short for A, and the output from the high-pass filter is called Detail, short for D. These outputs are half-sampled, in order to retain the same number of total samples form A and D as the number of pixels in the input image. This introduces some aliasing, which is compensated for when the signal is reconstructed from the wavelet coefficients. The digital filter coefficients relate to the wavelet shape being used. The approximation part of the signal can be further decomposed into new approximation and detail components, giving higher levels of decomposition. The process can be reversed at any level of decomposition, and the original signal can be reconstructed from these approximation and details. Through wavelet decomposition, the image can be decomposed into four sub-signals of different frequency band and direction at each level, they are the approximation and details of horizontal, vertical and diagonal sub-images, any of which can be extracted and processed solely.

3. MATHEMATICAL MORPHOLOGY THEORY

The basic morphological operations are erosion and dilation. Based on them, some important combined operations, such as opening, closing, opening residue and closing residue are defined. They are described as follows.

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Let \( f(x,y) \) be an input image, and \( b(x,y) \) a structuring element, \( (x,y) \) the coordinate of the pixel in image space. \( D_f \) and \( D_b \) be the definable areas of \( f \) and \( b \) respectively. The dilation and erosion operations to function \( f(x,y) \) by structuring element \( b(x,y) \) are defined by the following rules.

Erosion: \( f \rightarrow f \ominus b \), where
\[
(f \ominus b)(s,t) = \min\{f(s+x,t+y) - b(x,y) \mid (s+x),(t+y) \in D_f; (x,y) \in D_b\}
\]

Dilation: \( f \rightarrow f \oplus b \), where
\[
(f \oplus b)(s,t) = \max\{f(s-x,t-y) + b(x,y) \mid (s-x),(t-y) \in D_f; (x,y) \in D_b\}
\]

Opening by the structuring element \( b \) is defined as an erosion operation followed by dilation, and closing by \( b \) is dilation followed by erosion. That is

Opening: \( f \rightarrow f \circ b \), where
\[
(f \circ b)(x,y) = [(f \ominus b) \ominus b](x,y)
\]

Closing: \( f \rightarrow f \bullet b \), where
\[
(f \bullet b)(x,y) = [(f \oplus b) \oplus b](x,y)
\]

It is clear that an opening operation is anti-extensive, which has the ability to remove positive impulses and peaks smaller than the diameter of structuring element, and a closing operation can remove negative impulses and valleys. So we can define one operation based on subtraction. That is

Opening residue (Top-Hat): \( f \rightarrow hat(f) \), where
\[
hat(f) = f - (f \circ b)
\]

Top-Hat operator can suppress the smooth and large background patch and clutters, extract the point-target and noise whose shapes are analogy to the structuring element in high bright area. So it has the characteristic of the high-pass filter.

4. PRE-PROCESSING

A low-resolution infrared image with complex sea background must be pre-processed for the following process. This step includes the SSDL detection, vignetting correction and filtering.

4.1 The SSDL detection method based on wavelet

Generally, a small target in the long distance at sea surface always appears near the SSDL, according to which the area nearby the SSDL is delimited as the TPR, through which the search region of the point-target is reduced greatly and the strong wave and cloud clutters can be eliminated. Therefore, the SSDL is significant in the detection of targets at sea. However, there exists large number of high-radiancy-cloud-patch and wave glint, which forms strong horizontal background edges clutter while the SSDL is faint in the original IR image. If SSDL is detected directly, a lot of unnecessary information will be obtained, which makes it very difficult to locate the SSDL.\(^1\)

An approach for SSDL detection is proposed based on the wavelet transform in this paper. It is crucial to select the orthogonal wavelet base function, which makes the extracted edge features with irrelevance in the different scales and improves the accuracy of the detection and segmentation algorithm.\(^6\) Through many tests and comparison, a simplest orthogonal wavelet base, Daubecies (db1), also called Haar wavelet with strict support set, was selected and the approximation sub-image of the fourth level wavelet decomposition is extracted. Then a classical edge detection
algorithm, Sobel operator, is used to detect the horizontal edge and the image is thresholded to binary. Through searching the non-zero pixels and preserving the edges whose length exceed a pre-defined threshold, irrelevant pixels can be discarded. The primary SSDL is located by the returned parameters from the linked residual edges, the obtained SSDL in the sub-image and the number of decomposition levels. Probably, this SSDL has some deviation from its exact location. We can adjust it to its accurate position by designation an offset through experiment and experience. Take the SSDL as centre to construct two parallel lines on each side of it. The area between two parallel lines is delimited as the TPR. The results are showed in Fig.1.

It is necessary to explain that though the detection of SSDL has a little offset from its accurate position, it does not influence the results of target detection as the SSDL detection is only determining the TPR in the scene. When the SSDL is visible, the real point-targets can be retained in the TPR and the false outside the TPR can be discarded. Under the conditions of invisibility of the SSDL for the image outside or obscuration due to weather, process goes to the next step directly as the TPR is the whole view scene.

4.2 The vignette correction and filtering

An infrared image is often blurry. Spot target is dim and its edge is hazy, which is caused by the infrared sensor receiving the difference of radialization of the object and the surroundings for it is very sensitivity to the change of temperature, the radiation extinction and light scatters in the air, etc. Therefore we adopt a method, the row average grayscale subtraction (RAGS), in which the average intensity in vertical direction is computed firstly of each row, then the intensity average value of current row or the upper row is subtracted from each pixel value in a row to obtain an image with more uniform intensity, denoted by equation (6). This can correct the vignette caused
by non-linearity distribution of temperature, remove the random noise and enhance brightness of the spot target, as seen in Fig. 1(d).

\[ f'_i = f_i - \overline{f}_{i-1} \]  

(6)

Here \( f_i \) is the grayscale at pixel \((i, j)\), \( \overline{f}_{i-1} \) is the row average grayscale of upper row, and \( f'_i \) is the subtraction of them.

As the infrared image represents the thermal radiation difference between objects, the target's temperature is, usually, higher than that of the around objects, so the intensity of the infrared targets has higher value than that of neighborhood around area, and as an isolated bright spot in the image. So the point-targets and noise with high frequency, and the background is smooth and its pixels are correlative, with low frequency. According to this, a usual approach is employed as a high-pass filter to separate the targets in the high frequency domain from the background in the low frequency domain, as illustrated in Fig.2 (b) and (e), but which can not distinguish the target from noise. A morphology filter, Top-Hat operator, and skillfully combined the spatial and gray information, is adopted to execute filtering to reject clutter of the smooth and large background and disrelated structure and extract the infrared point target and a few noises in high intensity, as illustrated in Fig.2 (c). In this paper, we utilize Top-Hat filter to process image after the RAGS and it can procure the best results for suppress the background contribution and enhance the signal from targets, as described in Fig.2 (f).

5. DETECTION AND SEGMENTATION OF TARGET ALGORITHM

As described above, this algorithm is shown to improve the separation of targets and clutter based on some simple features. The method reduces the influence of clutters on the detection result, and is summarized as follows.

(1) To detect the SSDL and demarcate the target potential region.
(2) To implement RAGS in the sub-image slice of the target potential region.
(3) To choice a circular structuring element \( B_1 \) basis with the approximate shape of the targets, the morphologic Top-Hat filter is executed in the sub-image to suppress the background clutter and extract the point-target and noise in high brightness area.
(4) To select a proper structuring element \( B_2 \) according to the residual targets and clutter, the sub-image is followed opening operation to discard most small false alarms, through which a few potential targets can be obtained.
(5) Finally, to search the local maximum intensity and adaptive thresholding, the real target can be segmented. The grayscale levels were reduced greatly after above process and the contrast is increase, which makes the estimation of the threshold become easy and simple.
(6) To locate and sign the segmented target in the original IR image.

Altogether, the commonly failed detection is caused by the effect of a false alarm generated by a large high intensity reflection area of waves in the sunlight because of the limitation of the camera angle. So the false alarms usually occur closer to the camera and appear in the bottom of the infrared image and are away from the SSDL in real situation. The algorithm described above through detecting the SSDL and demarcating the TPR can remove the false alarms and insure the segmentation of the real point-target correctly.
6. RESULTS AND CONCLUSION

We tested our point target detection approach on various IR images. The original images, 768*576 size, are shoot with 8~12um wavelength infrared camera and then cropped into 400*400. The targets are navigating ships or naval vessels, and the background contains clouds, waves, coasts or maintains in the far distance. There is one target in the image and its size is between 3*3~30*30 pixels. This method was applied to 70 frames extracted random infrared images, and the detection results of all frames are correct. Fig.3 gives part of the results.

![Fig.3 The computer simulation results of detection](image)

(a) Original IR image; (b) The SSDL detection and delimited the target potential region (TPR); (c) The RAGS in the TPR; (d) The Top-Hat morphologic filtering; (e) The detection results.

The results indicate that the algorithm presented in this paper is chiefly deal with a single frame infrared image in whole view scene at the natural complex sea surface. Compared with the traditional methods, this algorithm has an efficient performance and can segment the targets in low SNR infrared images. In addition, the mathematic morphology has the properties of conciseness and preciseness and with natural parallel implementation structure. So it is easier to implement in real time. Because of the structuring element has greater influence on the results of detection and segmentation. How to select it adaptively is one of our further research directions.

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