Small Target Segmentation Algorithm Based on Wavelet Transform and Mathematics Morphologic

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***Abstract*—To detect and recognize the small targets under complex background, a new segmentation algorithm based on wavelet transform and mathematical morphology is presented. Firstly, the original image is decomposed in three levels by wavelet transform and the high-frequent images are fused by minimum mean square error algorithm to suppress the background and enhance the target. Secondly, the fused images are segmented with an adaptive threshold to get the centroid coordinates of the target area. Thirdly, the original images are segmented accurately with region growing algorithm to get the precise contours and centroid coordinates of the target area. The results of flight test show that the segmentation algorithm has high precision and accuracy, as well as strong engineering adaptability.**

***Index Terms*—WAVELET Transform, Mathematics Morphologic, small target, image segmentation**

I. Introduction

The recognition and tracking of small target in complex background plays a very significant role in monitoring and alarming system, and it is also the current domestic and international research focus. Small target segmentation, target contour extraction and centroid positioning are the bases and prerequisites of a variety of recognition and tracking algorithms. The recognition, assortment and track can work out only after segmentation. Since the target is far away from the observation point and its imaging size is only a few dozen pixels, what's more, the target is overwhelmed by the background clutter, it's extremely difficult and challenging to segment the target exactly from the complex background.

In this paper, a new algorithm of target segmentation which combines wavelet transform, adaptive threshold segmentation and the region growing of mathematical morphologic is proposed. Firstly, wavelet transform is used to preprocess the original image to suppress the background and show the target. Secondly, the processed image is segmented by an adaptive threshold and the coordinates of target centroid is achieved. Finally, the target centroid is regarded as the growing point， and the region growing algorithm is used to do the accurate segmentation of the original image. Then the accurate centroid and shaped features of the target are obtained for the later work of target recognition and track. After the coarse segmentation and the accurate segmentation, the target's contour will be more accurate which will benefit further identification and track work at a large extent.

Manuscript received October 17, 2012; revised May 20, 2013.

II. Preprocessing Algorithm Based on Wavelet Transform

Target recognition of a single resolution ratio image is likely to be affected by the background which would lead to false identification. Multi-sensor detection can solve this problem, however, it is limited by its expensive cost and complicated system. Considering those problems, this paper proposed a new algorithm to recognize the small target. Firstly, the wavelet transform is used to decompose a single frame image from a single sensor into several sub-graphs which have different resolutions. Then these sub-graphs are fused by the optimally weighted average values according to the theory of data fusion. In this manner, the background can be suppressed and the target will be outstanding, therefore, the small target could be recognized more easily [1].

A. Multi-Resolution Analysis of Wavelet Transform

The wavelet transform is developed on the basis of the Fourier transform since late 1980s which has a rigorous theoretical model. The wavelet transform has good localized nature in both time domain and frequency domain compared with the Fourier transform and window Fourier transform, so it can extract more effective information from the signal. Through dilation and translation operations, wavelet transform can focus on any details of the signal, so it is called "mathematical microscope". [2]

A family of wavelet function can be gotten by the basic wavelet function $\psi(t)$,

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t\text{-}b}{a}\right) \tag{1}$$

where a and b are constants, and a>0. In this formula a represents the telescopic-scale of the wavelet function, and b represents the pan-scale. If the telescopic-scale a is given as $a=2^j$, and the pan-scale b is given as $b=2^j k$, j k∈

doi: 10.12720/ijeee.1.2.76-79

Z, then the uniform discrete sampling can be achieved, and the wavelet function is transformed into dyadic wavelet.

$$\psi_{j,k}(t) = 2^{-j/2}\psi\left(2^{-j/2}t-k\right) \quad (2)$$

In this way, the dyadic discrete wavelet transformation of signal f(t) is:

$$(W_{\psi}f)(j,k) = 2^{-j}\int_{-\infty}^{+\infty} f(t)\,\psi(2^{-j}t-k)\mathrm{d}t \quad (3)$$

As two-dimensional image signal, wavelet transform has divisibility. The wavelet transform of two-dimensional image signal f(x,y) can be decomposed into two one-dimensional wavelet transforms along x and y directions. Firstly, the image is transformed along x direction, then along y direction similarly. Whereupon, four sub-images are obtained as Fig. 1 shows: a low frequency image signal A, a high frequency signal in the horizontal direction H, a high-frequency signal in the vertical direction V, and a high-frequency signal in the diagonal direction D. Both the complexity of the algorithm and the computing speed will be improved by choosing a small compact support wavelet function. Similarly, a further decomposition of the low frequent image signal can be done if the telescopic-scale is increased. By doing multi-decomposition of the low frequent image signal and extracting the high frequent signal, the multi-resolution analysis for two-dimensional can be achieved.

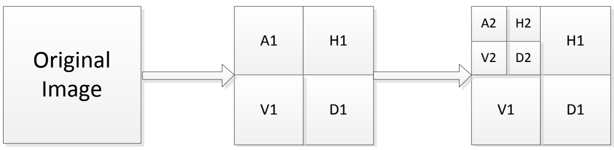


Figure 1. Two-dimensional wavelet transform

After three-decomposition of the original image by db3 wavelet, the background information is mainly shown in the low frequent image signal, and the feature of the target and the noisy information primarily existent in the high frequent. So the low frequent image signal can be ignored and the high frequent image signal can be reconstructed directly. This way, nine sub-images are ready for the following processing.

B. Image Fusion Algorithm

Image fusion is a process that a plurality of images of the same scene which are integrated to obtain further accurate information. Wavelet transform can decompose the original image into a series of sub-images having a different spatial resolution and frequency characteristics, because of its multi-scale and multi-resolution. And these sub-images reflect the local variation of the original image. In order to reveal the target and suppress noise, the sub-images in different decomposed layers and different frequency bands are fused in this paper.

Since there is a lot of noise in high-frequency images, the weighted average algorithm is involved in image fusion. And in order to outstand target and suppress noise better, the minimum mean square error algorithm is applied to calculate weight coefficients.

Supposing the No.i sub-image is I_i , and the weight is w_i .Then the fused image I is:

$$I = \sum_{1}^{9} w_i I_i \quad (4)$$

In order to facilitate the target detection, the minimum mean square error of fused image needs to be smallest. So

$$\sigma^2 = D\left(\sum_{i=1}^{9} w_i I_i\right) = \sum_{i=1}^{9} w_i^2\sigma_i^2 \quad (5)$$

should be smallest. And we should meet the formula below:

$$\sum_{i=1}^{3} w_i = 1 \quad (6)$$

This is a typical multi-variable extreme condition. So Lagrange multiplier approach is used to solve it.

$$w_i = \frac{1}{\sigma_i^2}\left(\sum_{1}^{3}\frac{1}{\sigma_i^2}\right) \quad (7)$$

After wavelet transform and data fusion, the image has a high signal-to-noise radio and it will be easy to segment the target from the background.

III. Adaptive Threshold Segmentation

In the paper, gray level of the target and background is almost the normal distribution after preprocessing. The background gray level is almost uniform and the gray level of the target is higher than background. In order to ensure the accuracy of segmentation, the improved minimum error algorithm is selected to calculate the segmentation threshold [3].

Assumed that the priori probability of the target and background in the image is $p_0(z)$ and $p_1(z)$, the mean is u_0 and u_1, and target pixels and background pixels accounted for a percentage of the total pixels is w_0 and w_1.

The probability of that target pixels wrongly classified as background pixels is:

$$e_0(T) = \int_0^T p_0(z)\,\mathrm{d}z \quad (8)$$

The probability of that background pixels wrongly classified as target pixels is:

$$e_1(T) = \int_T^{+\infty} p_1(z)\,\mathrm{d}z \quad (9)$$

Then the total probability of error is:

$$e(T) = w_0 e_0(T) + w_1 e_1(T) \quad (10)$$

The optimum threshold is the minimum threshold value of the total error probability. So the derivative of formula (11) should be 0. There will be:

$$w_0 p_0(\mathrm{T}) = w_1 p_1(\mathrm{T}) \tag{11}$$

For normal distribution:

$$p_0(\mathrm{z}) = \frac{1}{\sqrt{2\pi\sigma_0}} e^{\frac{(\mathrm{z}-\mathrm{u}_0)^2}{2\sigma_0^2}} \tag{12}$$

$$p_1(\mathrm{z}) = \frac{1}{\sqrt{2\pi\sigma_1}} e^{\frac{(\mathrm{z}-\mathrm{u}_1)^2}{2\sigma_1^2}} \tag{13}$$

Take formula (12) and formula (13) into formula (11), and calculate logarithm of the both sides of the formula:

$$\ln\frac{w_0\sigma_0}{w_1\sigma_0} - \frac{(T-\mathrm{u}_1)^2}{2\sigma_1^2} = \frac{(T-\mathrm{u}_0)^2}{2\sigma_0^2} \tag{14}$$

When

$$\sigma_0^2 = \sigma_1^2 = \sigma^2 \tag{15}$$

$$T = \frac{u_0+u_1}{2} + \frac{\sigma^2}{u_0-u_1} ln\frac{w_1}{w_0} \tag{16}$$

In the paper, the size of the original image is 240*320, while the size of target is smaller than 15*15. So the proportion of the target pixel w_0 is about 0.0005, and the proportion of the background pixel w_1 is about 0.9995. The mean gray level of the entire image u can be considered as the mean gray level of the background gray level u_1 because of the tiny proportion of the target pixels. The mean gray level of the target u_0 is about 1.3 times of the mean gray level of the entire image u. Threshold T according to the formula (14) takes the place of the target segmentation threshold. By means of assay, this algorithm can segment the target out from the background.

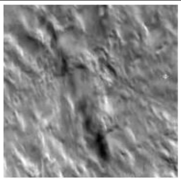
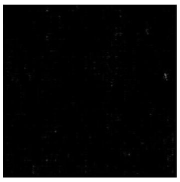
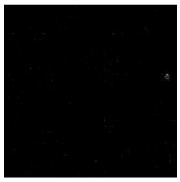
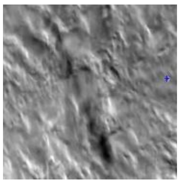
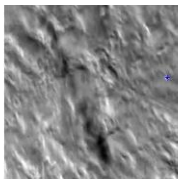
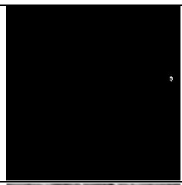
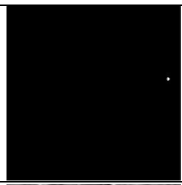
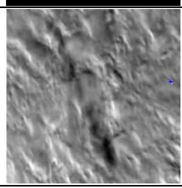
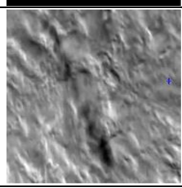
IV. ACCURATE SEGMENTATION based ON REGION GROWING

The basic principle of the region growing algorithm is to find an initial seed and then merge the similar nature into the seed pixels.[4] The specific algorithm is to find an initial seed point P in the image, then to search neighborhood area, when the gray-scale difference between the seed point and the searched point is less than threshold T, the searched point will be considered to belong to the same object, and be marked with L. Search the image with this principle, until the gray-scale difference is more than threshold T [5].

The region growing algorithm is simple to calculate, and it is quite fit for segmenting the uniform small structure. But it depends on the initial seed, and it is also sensitive to any noise [6].

In the paper, the initial centroid coordinates can be obtained after wavelet transform and adaptive threshold segmentation. Taking the centroid of the target as the initial seed, the accurate target can easily be segmented from the original image by using region growing algorithm. Then the accurate centroid coordinates and contour of the target can be obtained.

TABLE I. THE RESULTS OF FLIGHT TEST

Operate	Group one	Group two
Original image		
After wavelet decomposition and high-frequency image fusion		
After adaptive threshold segmentation(coarse-grained segmentation)		
After the morphological dilation		
The centroid of target area after coarse-grained segmentation		
After region growing segmentation (accurate segmentation)		
The centroid of target area after accurate segmentation		

The calculation process and the algorithm in the paper are given as below:

(1)Do three-decomposition of the original image using 'db3' wavelet transform, and reconstruct the high-frequency coefficients. Then nine high-frequency sub-images are obtained.

(2)Take the minimum mean square error as a criterion, calculate weight coefficient in accordance with the formula (8). Then fuse various high-frequency sub-images by their weights.

(3)Calculate the segmentation threshold in accordance with formula (14), then segment the fused image, and calculate the centroid coordinates of the target area.

(4)Take the centroid coordinates calculated in step (3) as growing point, use the regional growing algorithm to segment the target area accurately in the original image. And find out the exact centroid coordinates.

Table I shows that contrast of gray between target and background has been visible after wavelet transform and image fusion. The target can be segmented roughly from the background after adaptive threshold segmentation. But the size and shape of the target have changed substantially. After the accurate segmentation of the region growing algorithm, the size and shape of the target is almost the same as the original image.

V. CONCLUSION

Taking into account the target and background characteristics, the multi-resolution analysis capabilities of the wavelet transform and the comprehensive analysis capabilities of the image fusion are applied to suppress the background and enhance the target. For the purpose of extracting the accurate and complete target from the complex background, both the adaptive threshold and the region growing algorithm are used to segment the image. This algorithm has solved the problem of the small target image in the signal-to-noise ratio, the small amount of information and the difficulty in segmentation. The results of flight test show that the segmentation algorithm has high accuracy and strong engineering adaptability.

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