On Fusion Algorithm of Infrared and Radar Target Detection and Recognition of Unmanned Surface Vehicle

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Abstract

Aiming at the problems of unmanned surface vehicle (USV) target detection and recognition at sea, a detection and recognition algorithm based on wavelet domain image fusion method is proposed. The algorithm performs the target feature analysis of the acquired image, efficiently completes the preprocessing of denoising. Guarantee the detection effect of the target image and improve the fusion image quality. The infrared image is denoised by an ideal high-pass filter method, and the image is edge-detected by the Sobel operator. Combining wavelet transform and median filter to denoise radar target image, edge detection of images with Canny operator. Finally, wavelet domain fusion algorithm is adopted for infrared radar image fusion. The simulation results show that compared with the current classical infrared radar image fusion method, the fusion quality of infrared radar image in this paper is better. Improve the success rate of detection and recognition of sea targets, and provide valuable information for unmanned collision avoidance or further identification.

Key Words: Infrared Radar Image, Image Fusion, Wavelet Transform, Median Filter, High-pass Filter

1. Introduction

1.1 Motivation

Unmanned surface vehicle (USV) is a research hot-spot in recent years. Mainly used to perform dangerous and not suitable for the implementation of the task. It has a fast, small size, high degree of automation and intelligence features. In order to enhance the ability of USV to avoid collision, the key is to detect and identify the target at sea. Only by improving the success rate of detection and identification at sea targets, providing input for autonomous drone collision avoidance. Can improve autonomous performance of unmanned navigation.

The main means for imaging at sea include infrared, radar, visible light and the like. Infrared is designed for the night, rain and fog and other harsh climatic conditions. Navigation radar is one of the main detection devices on board can effectively detect longrange targets. Detection range up to tens of kilometers, and stable performance and high accuracy. But its shortcomings are the existence of blind spots, the target cannot be detected close range. In order for the USV to effectively avoid collision and provide accurate inputs, the target images detected by the infrared/radar are fused.

1.2 Previous Work

In the infrared target detection and recognition at sea, low pass filtering [1], high pass filtering [2], median filtering and other methods are usually used for image pre-processing [3]. In the infrared target detection, the traditional methods include statistical threshold segmentation, geometric and motion analysis, multiple scale wavelet transform, wavelet and so on. The methods for denoising radar target images include wavelet transform, median filter and fuzzy inference. The methods of image fusion include traditional multiple source image fusion, it based

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on wavelet transform method, it based on nonsampled contourlet (NSCT) fusion method. In order to extract the local spatial features of the target image, [4] introduced a feature based fuzzy reasoning system for the segmentation of infrared images. In order to realize the identification of the actual target ship and remove the non-target area, [5] proposed an efficient method for infrared image segmentation, which filters and separates two different filters. In order to complete the tracking of small targets such as surface torpedoes, [6] introduced a low signal to noise infrared image sequence detection of weak moving targets and tracking algorithm. After the image is preprocessed, the 3D spacetime scan result of the target is reduced to two-dimensional spaces. In order to make the edge of the image clearer, [7] proposed a multiple-dimensional image edge extraction method based on binary wavelet transform applied to remote sensing image samples. However, in the two-dimensional image sequence detection of strong scattering point method, the subsequent study based on the strong scattering point of the target structure features extracted to achieve the target sequence image recognition [8]. In order to further enhance the realtime processing capabilities of large scale images, based on the study of median filtering, [9] proposed an improved fast median filtering algorithm based on mean division method. The edge detection algorithm based on Canny operator and threshold segmentation makes the edge of the extracted image clearer [10,11]. In order to achieve better noise cancellation, [13] proposed the multiple scale transform characteristic of wavelet transform and applied it to the SAR with noisy images to effectively separate the signal and noise. In order to improve the target recognition rate, [14] proposed a target recognition algorithm based on the improved D-S evidence combination rule, which has strong anti-jamming performance and can effectively fuse various conflict-information. However, they have the disadvantages of low fusion quality and low definition.

In order to obtain better infrared radar image fusion effects and speed up image fusion. This paper proposes an infrared radar image fusion method based on wavelet domain fusion. The results show that compared with the current classical infrared radar image fusion method. This method can not only make full use of the original image detected by radar, but also has a simple detection algorithm, a small amount of calculation, and a better image fusion effect. It can provide valuable information for unmanned collision avoidance or further identification.

2. Research on Target Detection and Recognition Algorithm Based on Sea Surface Infrared Image

2.1 High Pass Filtering and Image Enhancement

Because the part of the image in which the grayscale suddenly changes corresponds to the high frequency component of the spectrum, the high pass filter is used to attenuate the low frequency component and make the high frequency component clear and the image can be sharpened. The high pass filter used in this paper is the ideal high pass filter. It is to let the Fourier transform the high frequency components, to maintain the relative high frequency components, while reducing the frequency of low frequency components. So as to enhance the edges and details of the image, the image edges and details more clearly.

High pass filter can only remove the low frequency noise. In order to further filter out high frequency noise and clutter and enhance small targets, image enhancement techniques can be introduced for subsequent processing. The contrast enhancement techniques that can be used to process infrared images include two methods: linear transformation and non-linear transformation.

Linear grayscale transformation will be a certain region of grayscale linear conversion to another region. If the gray value of the original image \( f(x, y) \) is \([m, M]\). It is desirable that the grayscale range of the changed image \( g(x, y) \) be \([m, M]\). To contrast the image to make a more refined adjustment, and then can be used segmentation linear transformation. That is, different gray level segments to make different adjustments, some compression, and some stretching. Therefore, a linear method is used to maximize the contrast of the image. The transformation equation is as follows:

\[
g(x, y) = \begin{cases} 
  k_1 f(x, y) + b_1 & 0 \leq f(x, y) \leq f_1 \\
  k_2 f(x, y) + b_2 & f_1 < f(x, y) \leq f_2 \\
  k_3 f(x, y) + b_3 & f_2 < f(x, y) \leq f_3
\end{cases}
\]
where \(k_i\) \((i = 1, 2, 3)\) represents the slope of the \(i\)-th line.

Non-linear grayscale transformation is the non-linear grayscale value of a certain area to another area. The actual value is to use \(\gamma\) grayscale correction. Let \(f\) be the original gray level of the image, \(\gamma\) be the intensity of incident light of the CCD image sensor. The relationship between the input light intensity and the output signal can be expressed as follows:

\[
g = k \left( \frac{f}{\epsilon} \right)^{\gamma}
\]  \((2)\)

where \(k\) is a constant, usually take 1; the \(\gamma\) value specifies the shape of the curve that maps the brightness value of the image. When \(\gamma < 1\), the brighter the input, the larger the output value; \(\gamma > 1\), the brighter the input, the weaker the output value; when \(\gamma = 1\), non-linear transformation into linear transformation.

Sharpening uses a linear Laplace, which is a linear quadratic differential operator with rotational invariance. More suitable for improving the image blur due to the diffuse reflection of light, enhancing the edge processing effect, reducing or eliminating the low frequency component of the midpoint of the image without affecting the high frequency component. Filter out these low frequency components to make the image increase the contrast, the edge is obvious, suitable for detection and identification.

### 2.2 Image Segmentation Based on Sobel Edge Detection

Since the edge of the object is reflected by the gray level discontinuity, the general edge detection method is to examine the change of the gray level of each pixel of an image in a certain area. Edge detection using the adjacent first order or second order derivative of the law to detect changes in the edge, this method is often referred to as the edge detection of local operator. The commonly used edge detection operators are gradient operator, Robert edge detection operator, Prewitt operator, Sobel operator and Laplace operator. In this paper, Sobel operator is used to investigate the change of the gray level of each pixel in a certain region. Because both are differential image and filtering operations, making the image processing grayscale gradients and noise suppression has two good results. At the same time, the edge location of two operators is more accurate and complete, which also has a positive impact on image segmentation. Sobel operator is a gradient detection operator, the gradient corresponds to the first derivative and the first derivative of the digital image is the gradient of the image. The operator contains two sets of 3\(\times\)3 matrix, which are horizontal and vertical, respectively, and then plane convolution with the image to obtain the approximate values of the difference in horizontal and vertical brightness, respectively. The approximate values of the horizontal and vertical gradients of each pixel of the image can be calculated by the following equation, and the size of the gradient is calculated.

\[
G = \sqrt{G_x^2 + G_y^2}
\]  \((3)\)

Sobel operator uses adjacent pixels to calculate the gradient, which can reduce the algorithm’s response to noise and has a certain anti-noise ability. Compared with the Prewitt operator and Sobel operator, the weighted operation of the pixels near the \(x\) and \(y\) axes improve the edge to edge ratio of the algorithm. In general, the Sobel edge detection algorithm performs well both in accuracy and in noise immunity, and is computationally simple and is the most widely used in image preprocessing.

### 3. Research on Target Detection and Recognition Algorithm Based on Sea Surface Radar Image

#### 3.1 Sea Radar Image Denoising

In order to remove the clutter and co-channel interference at the same time to retain the integrity of the target information. In this paper, the method of median filter and wavelet transform is used to complete the denoising. Because median filtering can effectively suppress impulsive noise, wavelet threshold denoising method can restrain Gaussian noise. For the image contains Gaussian noise and impulse noise, the combination of the two is a very good choice.

Median filter is a non-linear noise removal method. It is defined as a set of digital \(x_1, x_2, \ldots, x_n\) and the \(n\) values are arranged in order according to the value: \(x_{11} \leq x_{12} \leq \ldots \leq x_{1n}\)

\[
y = \text{Med}\{x_1, x_2, \cdots x_n\}
\]  \((4)\)
where $y$ is called the median of sequences $x_1, x_2, \ldots, x_n$.

The wavelet is obtained by scaling and shifting the basic wavelet. Continuous wavelet transform is also called integral wavelet transform, defined as wavelet transform:

$$W_f(a,b) = \left\{ f, \varphi_{a,b}(x) \right\}$$

$$\int_{-\infty}^{\infty} f(x) \varphi_{a,b}(x) \, dx = \int_{-\infty}^{\infty} f(x) \varphi_{a,b} \left( \frac{x-b}{a} \right) \, dx$$

The inverse transformation is:

$$f(x) = \frac{1}{C_q} \int_{-\infty}^{\infty} W_f(a,b) \varphi_{a,b}(x) \frac{da}{a^2}$$

Wavelet transform and median filtering in combination with the denoising process shown in Figure 2. The 3*3 diamond window radar image median filtering. When the absolute value of the wavelet coefficient is less than the selected threshold, it is rounded off to zero. When the absolute value of the wavelet coefficient is greater than or equal to the threshold, the coefficient is taken as the difference or sum of the wavelet coefficient value of the point and the threshold. The key technologies are to select the wavelet base in terms of linear phase, vanishing moment, similarity and tight support, so as to ensure the most suitable parameters are selected. Finally, the pre-processing effect is objectively evaluated by the peak signal to noise ratio.

### 3.2 Segmentation of Objects Based on Canny Edge Detection

By detecting different regions in the image edge detection can achieve the purpose of segmentation images. Therefore, this thesis uses the edge detection method to segment the image and detects the image with Canny edge detection operator. Canny edge detection algorithm is the most perfect edge detection algorithm in the classic theory, the best. Canny proposed three good criteria that edge detection algorithms should satisfy: signal to noise ratio criteria, positioning accuracy criteria, unilateral re-
sponse criteria, and lists the function representation. Which need to improve the signal to noise ratio smoothing filter to eliminate noise. However, the smoothing effect of the filter will also be applied to the edge of the pixel, image edge blur effect detection accuracy.

First set up two-dimensional Gaussian function, at each point to calculate the local gradient and edge direction. The edge point is defined as the point whose intensity is locally largest in the gradient direction. Determine the edge point will lead to the emergence of the ridge in the gradient amplitude image. The algorithm tracks the top of all ridges and does non-maximum suppression. Then find an edge point or line connection based on the image of each point in the connected neighborhood. The algorithm completes the segmentation of the target by integrating the connected weak pixels into the strong pixels and completing the edge connection. Canny operator adopts the double threshold method to finalize the edge information of the image. Get edge information according to high threshold. But it contains noise and other interference information, but also because part of the edge information is filtered out; leaving the target edge is not closed. When the target edge is not closed, the low threshold can be complemented to find a complete and accurate target edge.

4. Infrared/Radar Image Fusion

A set of images obtained by the original infrared image processing in section 2 and the images obtained after SAR image processing in section 3 are fused by a wavelet domain fusion method.

Let \(f(x, y)\) represent the original image, denoted as \(C_0\). Let the scale coefficient \(\phi(x)\) and the filter coefficient matrix corresponding to the wavelet coefficients \(\psi(x)\) be \(H\) and \(G\), respectively, then the wavelet decomposition algorithm is:

\[
\begin{align*}
\mathbf{C}_{j+1} &= H' \mathbf{C}_j H' \\
D_{h_{j+1}}^h &= G' \mathbf{C}_j H' \\
D_{v_{j+1}}^v &= H' \mathbf{C}_j G' \\
D_{d_{j+1}}^d &= G' \mathbf{C}_j G'
\end{align*}
\]

(10)

where \(j\) represents the decomposition layer; \(h, v, d\) denote horizontal, vertical and diagonal components respectively; \(H'\) and \(G'\) are conjugate transpose matrix of \(H\) and \(G\) respectively. Wavelet reconstruction algorithm:

\[
\mathbf{C}_{j-1} = H'C_j H + G'D_j^h + H'D_j^v + G'D_j^d \quad (11)
\]

5. Simulation Results and Analysis

5.1 Infrared Radar Image

In order to test the infrared radar image fusion effect in the wavelet domain, simulation was implemented using MATLAB R2015b software programming. Select two \(346 \times 346\) images as fusion objects, as shown in Figure 3. Choose the current classic infrared radar image fusion method for comparison testing. They are wavelet transform multi-focus image fusion, weighted average image fusion [15], and PCA image fusion method [16]. First complete the preprocessing of infrared images. Using an ideal high-pass filter to denoise the image makes the edges of the image clear. The linear sharp Laplacian operator is used for image sharpening. The segmentation method of Sobel operator edge detection is used to complete the edge segmentation of the image. As shown in Figure 4.

Second, complete the radar image preprocessing. Radar image denoising method based on wavelet transform

![Figure 3. Original infrared radar image.](image)

![Figure 4. Infrared image preprocessing.](image)
and median filter method. Using 3*3 diamond window radar images by wavelet transform combined with median filter processing and use of the global threshold denoising function. Canny edge detection operator detection image, determine the edge point will lead to the gradient amplitude image of the ridge. The algorithm tracks the top of all ridges and does non-maximum suppression. Then find edge points or line connections according to the image of each point in the connected neighborhood. The final algorithm completes the segmentation of the target by integrating the connected weak pixels into the strong pixels and completing the edge connection. The Canny edge detection algorithm, which can be seen in Figure 5, keeps the edges of the image clear and consistent.

5.2 Results and Analysis

The infrared radar image fusion results of all methods are shown in Figure 6. Using the standard deviation, spatial frequency, sharpness and information entropy, four performance parameters to evaluate the image fusion quality. The standard deviation reflects the degree of dispersion of image pixel values and the mean value. The larger the standard deviation, the better the image quality. The spatial frequency reflects the number of repetitions of the detail feature over the length of the unit. The greater the spatial frequency, the more image information, the more clear the image. Sharpness refers to the clarity of the details of the image and its boundaries. The greater the sharpness value, the higher the image quality and the clearer. Information entropy describes how much information an image contains. The larger the information entropy, the higher the quality of the fused image. From Table 1, we can see whether it is standard deviation, spatial frequency, sharpness, or information entropy. In this paper, the infrared radar image fusion results have been improved to different degrees. This shows that the fusion quality of infrared radar image in this paper is good, and the fusion effect has obvious advantages.

6. Conclusions

In order to improve the quality of the image fusion of the UAV infrared radar target detection. This paper proposes a wavelet domain infrared radar image fusion strategy. Comparative experiments show that compared to the current classical infrared radar image fusion method. This method effectively solves the problems of current infrared radar image fusion process. It can meet the prac-

![Figure 5. Radar image preprocessing.](image)

![Figure 6. Comparison of infrared radar image fusion effects with the current classic method.](image)

<table>
<thead>
<tr>
<th>Fusion method</th>
<th>Standard deviation</th>
<th>Spatial frequency</th>
<th>Sharpness</th>
<th>Information entropy</th>
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<tbody>
<tr>
<td>Figure 6a</td>
<td>38.01</td>
<td>40.46</td>
<td>19.07</td>
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<tr>
<td>Figure 6b</td>
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<td>31.46</td>
<td>11.24</td>
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<td>Figure 6c</td>
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<td>26.73</td>
<td>10.15</td>
<td>6.19</td>
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<td>Figure 6d</td>
<td>36.68</td>
<td>28.08</td>
<td>10.38</td>
<td>6.18</td>
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tical application requirements of infrared radar image fusion and improve the image fusion effect and quality. It is expected that the fusion image quality with deep learning will be the further research direction.

References


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