Journal of Shipping and Ocean Engineering 7 (2017) 186-191
doi 10.17265/2159-5879/2017.05.002

Wavelength Estimation Method Based on Radon Transform and Image Texture

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Abstract: In order to overcome the shortcoming of poor accuracy and non-serious intuitivism of traditional wavelength calculation method in serious noise, a revised Radon transform algorithm is proposed by using a straight-line instead of using the wave's texture approximately applied to wavelength estimation. Firstly, Radon transform of the radar image is analyzed. Then, to obtain its fitting straight line combined with wave texture, the distance is calculated between straight lines to get the wavelength. Finally, the algorithm is programmed with Matlab on PC. The experimental results show that the proposed algorithm can improve the estimation accuracy of the wavelength with good visibility.

Key words: Radar image, Radon transform, image texture, wavelength.

1. Introduction

Understanding and mastering the data and variation rules of marine dynamic environment factors are very important for marine environmental monitoring, research and development, reducing the probability of maritime accidents and increasing the success rate of search and rescue. For example, for maritime search and rescue, most of them are carried out under the conditions of bad weather and sea conditions. The first step is in the search and rescue is to determine the scope of search, which covers all possible survivors [1]. However, the sea surface flow field will cause the search and rescue target to move or drift, so the further determination of the search and rescue region depends on the reliable marine environment information [2]. This paper focuses on the wavelength in the ocean dynamic environment.

In the study and analysis of the marine dynamic environment elements, the extraction of wavelength information has been a crucial technology [3]. Usually the spectrum of ocean waves is analyzed, or the wavelength of ocean waves is derived from the wind factor according to the wave data and the relationship between the wind elements and the wave elements. Common methods are 2D-FFT (two-dimensional Fourier transform) [4], 1D-FFT (one-dimensional Fourier transform) [4], X-band navigation radar, ocean wave image spectrum method [5], etc. The navigation radar can image the ocean surface wave. When waves travel over the sea, the peak radar echoes usually have higher amplitudes than the wave trough, that is, they are shown as light and dark stripes on marine radar images, and ocean wave textures contain the wave length information and propagation direction information of ocean waves that displayed on the navigation radar image stripes of light and shade. Texture contains the information of wavelength and waves propagation direction. However, due to the randomness of the waves, the accuracy of retrieving the wavelength of ocean waves needs to be mentioned, and not visualized.

To solve this problem, based on the Radon transform of X-band radar images, this paper proposes the wavelength combination method to estimate the wave texture. The experimental results show that the algorithm accuracy is improved and it has a good

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application prospect and significance to the development of maritime search and rescue, the estimation of ocean currents in oil pollution diffusion, the safety guarantee and route selection of ship transportation at sea [6-8].

2. Common Wavelength Estimation Method

2.1 1D-FFT

The basic idea of the method is to calculate the wavelength of ocean wave by using the wave correlation function. Firstly, to obtain the power spectrum of the image is by way of 1D-FFT of the sea wave image. Then, the inverse Fourier Transform can obtain its correlation function, and find out the distance between the origin of the correlation function and the first maximum point, and then the wavelength of the wave can be obtained. In order to improve the speed of operation, the Fourier Transform can be carried out by sampling the four sampling values in the particular direction of the ocean wave, and the distance between the original of the wave's correlation function and the first maximum point is the wavelength of the wave.

The method of Fourier Transform of the image, extracts the texture features by wavelength Fourier coefficients, however, various points on the frequency domain graph can generate motion because of the existence of noise, and cannot correspond to the time domain image in a single way, resulting in greater errors.

2.2 2D-FFT

The basic idea of this method is to calculate the wavelength using the two-dimensional spectrum of wave image. First, the 2D-FFT of wave image is used to obtain the spectrum of the image. Then, the position of the maximum point (the main frequency of wave) is found, and the direction and the wavelength of the wave propagation are obtained. The basic formula is as follows:

$$L = N \cdot \Delta x / \left(u_m^2 + v_m^2\right)^{1/2} \tag{1}$$

$$\theta = arctan\left(v_m / u_m\right) \tag{2}$$

Among them:

L: Wavelength;

θ: Wave direction;

u_m , v_m : Maximal points coordinates in the frequency domain;

N: Sample numbers of wave images;

Δx : Sampling interval.

The analysis of formula shows that there are some disadvantages:

(1) The method needs 2D-FFT of the image, getting the frequency components of each point, however, it only adopts the components near the maximum frequency in the process of calculating wavelength, so amount of calculation is large relatively.

(2) Because of the noise in the image, in the frequency domain image, the spectral distribution in the vicinity of the maximum point is flat, and it is difficult to find out the maximal points in frequency, which can lead to errors. When the image is manipulated by using smoothing filter, it would change the location of the maximum point. With the change of the size of the smooth template, the fluctuation range of the wavelength is also larger, which is not conducive to the subsequent calculation. Therefore, only when the filter or smooth template is not performed, the range and error of the results are relatively small. The difficulty of this algorithm is the selection of window size, and the selection of image processing window is too large, which will have different wave direction and wavelength texture in the window, resulting in unclear analysis results. If the image processing window is too small, the window will not contain a complete wave texture to make the wave information incomplete.

3. Wavelength Estimation Based on Radon Transform

3.1 Radar Image Preprocessing

In order to reduce the influence of image noise on wavelength estimation and improve the processing speed, firstly, the sub-image is taken in the original radar image, and the sub-image is too large for quick processing of the image. Then, in order to enhance the wave texture of radar image, it needs to attenuate the background of gray value gradient. Hereby, it is handled by Sobel operator. At last, setting the threshold *T* makes the image clear.

3.2 Radon Transform

In a two-dimensional space, the Radon transform is the transformation method that computes the image function $f(x,y)$ on the same plane and is projected along the specified angle ray direction, which is defined as:

$$R_\theta(x') = \int_{-\infty}^{\infty} f(x'\cos\theta - y'\sin\theta, x'\sin s\theta + y'\cos\theta)dy' \qquad (3)$$

In the formula, $R_\theta(x')$ indicates the integral result, $\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$.

In the Radon transform figure, the angle position coordinates of every high spot correspond to one or more of the original linear. Once these high spot values are found, the linear texture direction can be detected in original image. According to the characteristics of wave crest and valley in the nautical surface image of X-band, the radar image is transformed by Radon transform directly, and the detection of wave peak is transformed to the detection of the highlights of Radon field. Therefore, the navigation radar image of the waves can be processed according to the texture analysis method to get the wavelength. The X-band radar sea clutter image has rich wave information, and Radon transform [9] is used to obtain the wavelength. But the calculation of this algorithm is large and not intuitive. Aiming at this problem, this paper proposes an algorithm to replace the wave texture with the linear approximation, and the wave texture detection is transformed to a straight line detection. The Radon transform of image transforms the time domain problem into the line parameter domain analysis, that is, the detection of the straight line can be equivalent to the detection of the highlights and dark spots in the Radon domain [10]. Viewing the original radar image and removing the line are inconsistent with the texture direction.

3.3 Mark the Corresponding Line of Texture

The propagation of the waves is irregular, that is, the direction of the wave and the size of the wavelength will change, so in the analysis, the following hypothesis should be made:

Firstly, in time and space, the sea surface fluctuation is a random process, and this random process has the uniformity, stability and ergodicity. Then, assuming that the wave moves forward, the crest line (or the trough line) is a straight line. At last, the relationship between two lines can be used to calculate the wavelength.

Each line in the image has a peak in the position of corresponding line parameters. By Radon transform to find n maximum points of the peak *R*, and the corresponding line, indicate the image of the maximum value and the wave texture are plotted on the Radon transform and the pretreatment image. The geometrical relation and distance between these lines are analyzed and the wavelength is estimated. The algorithm is shown in Fig. 1.

4. Experimental Results

The two-dimensional distance and azimuth radar echo images used in the experiment are achieved through the AD converter. The pixel value of radar image is the amplitude of radar echo, and its gray value is 256 (8 bits). Radar using 3 nm range and intermediate pulse to detect targets, pulse width is 0.1

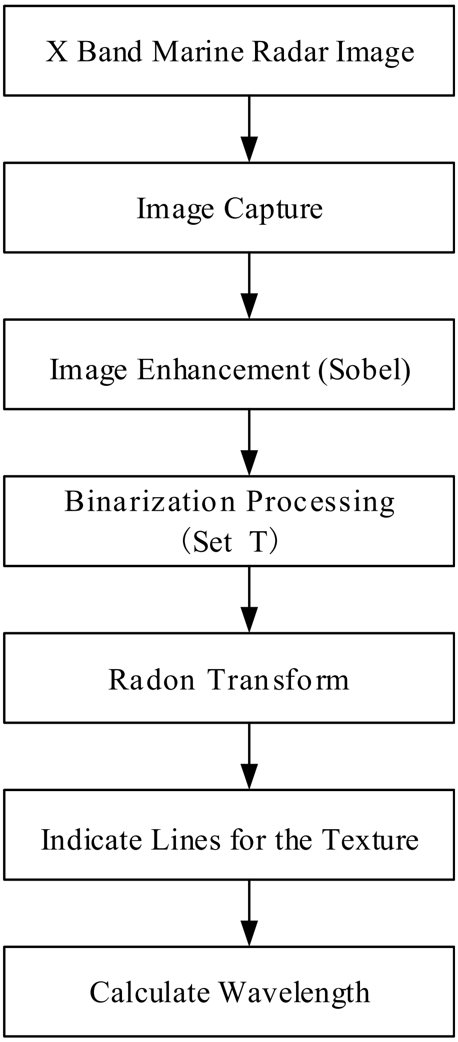

Fig. 1 Wavelength estimation schematic.

μs, the size range of quantitative unit is 6.67 m, the size of the location of quantitative is 0.088°. A radar target echo occupies a quantitative unit, and a radar image is recorded every 3 s. In order to reduce the difficulty of estimating precision and improve the accuracy, the selected experimental image data are the waves with regular waveforms.

Ten radar images were selected for analysis after several sea experiments. The image size is 2,048 × 2,048, as shown in Fig. 2. The experimental site is about 5 miles southeast of the chicken bone reef at Yangtze River estuary. The wave height is 4 meters high and the measured wavelength is 45.1 meters.

First of all, the original radar image sequence is preprocessed to select the image of the same location in the image sequence for the convenience of image processing and calculation. Sub-image capture size is 64 × 64 pixels, where the intercept position is obvious in the wave texture, and the position of each radar image is: (1200, 886), (1263, 886), (1200, 949), (1263, 949). Fig. 3 is the tenth sub-image of the radar image. Next is the enhancement processing of the sub-image, and setting a threshold value T = 32, making the radar image texture clear under binarization processing, as shown in Fig. 4. After image preprocessing, taking a Radon transform finds out the 13 largest peak points and its corresponding straight line. The most value points are marked on the Radon transform figure, as shown in Fig. 5. Marking the straight lines corresponding to all image textures, as shown in Fig. 6, and removing the straight lines are inconsistent with the direction of the image texture.

Table 1 shows the processing results of the ten radar images by way of three algorithms. From the above analysis, using 2D-FFT method to calculate the wavelength, choosing 3 × 3, 5 × 5 pair window for image median filtering processing, the wavelength range fluctuation is bigger, frequency position will move,

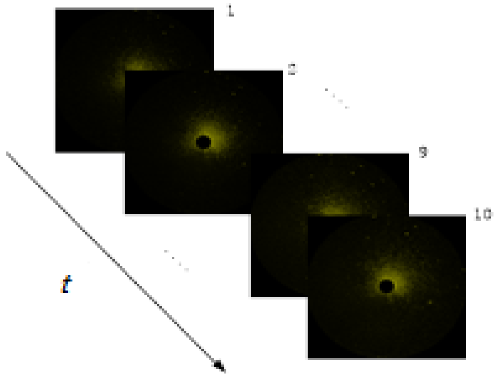

Fig. 2 Original radar image sequence.

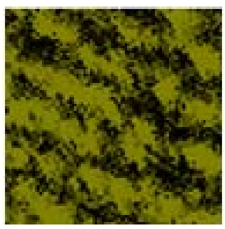

Fig. 3 Radar sub-image.

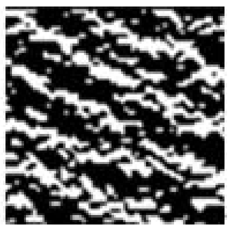

Fig. 4 Image after preprocessing.

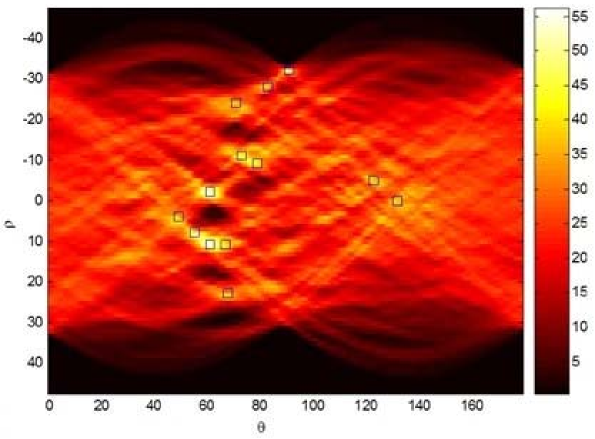

Fig. 5 Radon domain image results.

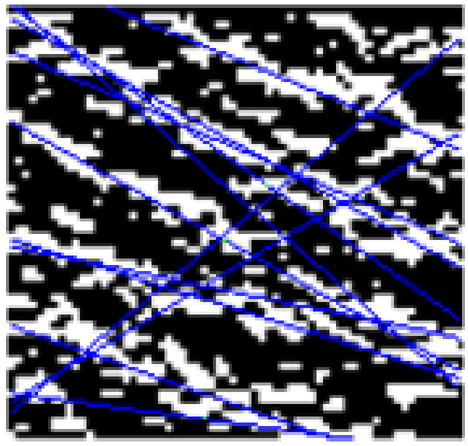

Fig. 6 Waves texture corresponding linear.

Table 1 Wavelength processing results (unit: meter).

Image sequence number	1D-FFT algorithm	2D-FFT algorithm smooth template size		Algorithm of paper
		3*3	5*5	
39	72.76	153.72	80.37	49.54
40	67.16	143.53	72.95	47.30
41	65.71	138.91	71.73	44.78
42	66.83	143.55	72.74	47.03
43	65.15	138.62	71.71	44.61
44	64.04	138.18	71.18	44.41
45	65.89	142.95	72.65	46.91
46	62.83	135.09	70.95	41.86
47	63.51	135.18	70.99	42.02
48	62.50	134.99	70.18	41.59

and the corresponding wavelength estimation range is larger. Using the 1D-FFT method to calculate the wavelength, the various points on the frequency domain cannot correspond with the time domain image, causing the error and the linear fitting is more troublesome and not intuitive. The algorithm proposed in this paper overcomes the shortcomings of the above two methods, such as indirectness and error, which can improve the accuracy of the wavelength estimation.

5. Conclusions

In this paper, based on the Radon transform, the wavelength is estimated by the change of radar image texture. As the observation and treatment method for the wavelength of marine dynamic environment factors, the algorithm time cannot be too long, nor has a large amount of calculation. The experimental results show that the Radon transform combined with wave texture to obtain its fitting line method overcomes the disadvantages of the 1D-FFT method and the 2D-FFT method. According to the analysis, the algorithm enhances the accuracy of the wavelength estimation, reduces complexity, and has very good intuitiveness.

Acknowledgements

The research is supported by Shanghai Shuguang Plan Project (No: 15SG44) and NSFC of China (No: 51379121, 61304230, 51709167).

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