CHAPTER 290

Application of Satellite Images to the Detection of Coastal Topography

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Abstract

Taking advantage of the high resolution visible images from the remotely sensed data of SPOT, the phenomenon of waves in the coastal area of Taichung was analyzed and its changing characteristics were studied. Changes of wave direction are affected by coastal topography; therefore, the changes of water depth can be detected by waves characters. In this study, the P band image data of SPOT of Taichung coast taken on 8th December 1993 was used. After dividing the area from deep to shallow into several blocks, each with 128x128 pixels, the wave images were transformed into two dimensional wave number spectra by ways of Fourier Transform. After that, the wave direction and the wave length were calculated. Results show that the shallower the water depth, the shorter the wave length; and the wave rays tend to approach shore normally. The phenomenon coincides with the theorem of wave dispersion. At last, based on the Snell's Law and the theory of shoaling, the average depth of each block was calculated. The results are encouraging.

Introduction

Remote sensing techniques have been developing rapidly since 1970. Since then, the LANDSAT, SEASAT and the SPOT satellites, have been launched and operated. The earth resources satellite receiving station in Taiwan was also installed in 1993.

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In recent years, many researchers are using this new techniques to solve problems in the field of Oceanography, J. Populus (1991) used SPOT data to do the wave analysis. P.N. Bierwrith (1993) tried to detect depths on shallow water by studying the radiance of sea bottom reflectance. SPOT satellite is a sun-synchronous salelite with an average orbit height of 832 km. It passes Taiwan at 10:45 A.M. and reappears at the same track every 26 days. Since SPOT has the ability of inclined scan, we are able to get information of the same area every 3~5 days. The XS band image has a spatial resolution of 20 meters, and P band image has a spatial resolution of 10 meters. This study try to detect water depth at intermediate depth zone by using the characteristics of wave propagation.

Background Theory

The Dispersion equation states that

$$C^2 = \frac{g}{k} \tanh kh \tag{1}$$

where
C : wave celerity
σ : the angular frequency
k : wave number
g : gravitational acceleration
h : depth

During the propagation of waves from deep sea to shallow water zone, wave height, wavelength and wave direction undergo changes due to changes of water depth. In region with intermediate water depth, we have

$$L = L_0 \tanh kh \quad ; \quad C = C_0 \tanh kh \tag{2}$$

where L_0 , C_0 = wavelength & wave celerity in deep water

The irrotationality condition of wave number k yields

$$\frac{\partial(k \sin\theta)}{\partial x} - \frac{\partial(k \cos\theta)}{\partial y} = 0 \tag{3}$$

where θ is the angle between wave ray and the normal of coastline.

For a coast with straight and parallel contours, the changes of the wave direction obey the Snell's law :

$$\frac{\sin\theta}{c} = \frac{\sin\theta_0}{c_0} \tag{4}$$

By using all the above equations and the data from satellite image, the variations of the water depthes at different locations can be estimated.

Techniques Used

Although the wave patterns are visible roughly in the satellite image, its real direction and wavelength can not be measured by eyes. Therefore, certain techniques of wave-number spectrum analysis using the two-dimensional Fourier transform are required. From the satellite image, we obtained the wave-number spectrum $S(k) = S(k_x , k_y)$. If $I(x , y)$ stands for the spatial intensity of the image, then the wave-number spectrum can be obtained by using the two-dimensional Fourier transform as

$$S(k_x , k_y) = \iint I(x , y)\, e^{-jk_x x - jk_y y}\, dxdy \tag{5}$$

When the spectrum peak was calculated, the wavelength and wave direction in each subregion can be determined as follows :

$$\frac{2\pi}{L} = k = \sqrt{k_x^{\ 2} + k_y^{\ 2}} \quad ; \quad \theta = \tan^{-1}(k_x / k_y) \tag{6}$$

where k_x , k_y = the wave number components of the peak position on the spectrum diagram; θ = the angle between the wave direction and the Y-axis.

The above method is suitable for cases where wave phenomenon is simple and significant. If there is noise on the image scene, for example, a boundary of different water colors exists. We'll get a confused spectrum. In such cases we have to use special techniques, such as top-hat transform, to reduce the influence of noise. Fig.1 & Fig.2 show the comparison of the original image scene and the image after using Top-hat transformation, a detail flow chart of processing is shown in Fig.3.

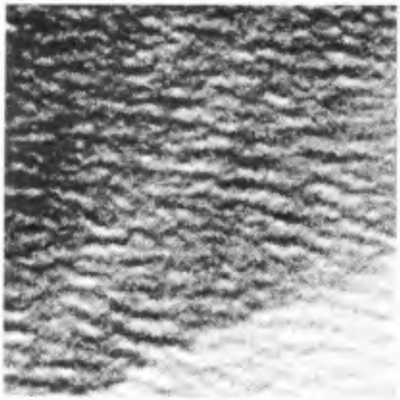

Fig. 1 Original image scene of the sea

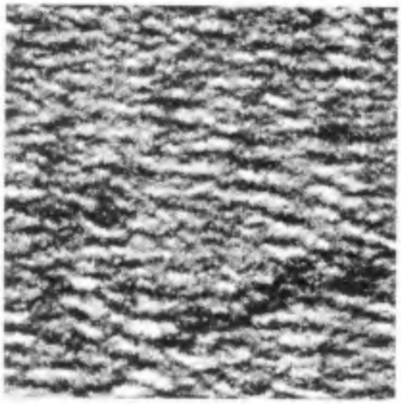

Fig. 2 Image scence after using Top-hat transformation

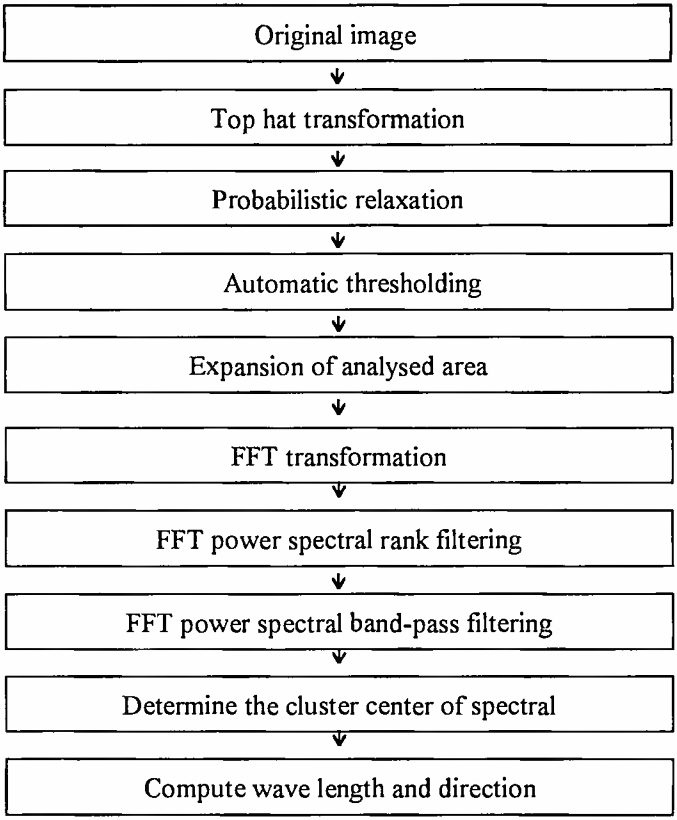

Fig. 3 Detail flow chart of processing

Fig. 4 Satellite images off Taichung Coast

Results

In this study, the Pan Band image data off Taichung Harbour on 8th December, 1993 were used (Fig.4), it covers an area of 18km x 12.5km. Taichung Harbour was builded on 1970's, locate at the central western coast of Taiwan. From September to March, the winter monsoon season, the strong wind always blows from north. Therefore, the waves travel from the upper to the lower in Fig.4. The upper left corner is 9 kms away from coast and the depth is about 50 meters. The lower left corner is the outlet of Da-Du River and is quite shallow. Therefore we can observe the phonomenon of waves shoaling. After selecting and dividing some scope in the left part area from deep to shallow water and labelling them as A, B, ... S, with each block having 128x128 pixels, the wave image is then transformed into the wave-number spectrum.

Two example diagrams of the wave-number spectrum at block E (in deep water) and S (in shallow water) are shown in Fig.5 and Fig.6 respectively. In these figures, the longer the distance of the bright spot to the original point, the larger the wave number, which means shorter the wavelength.

Fig. 5 Wave image & wave number spectrum at block E

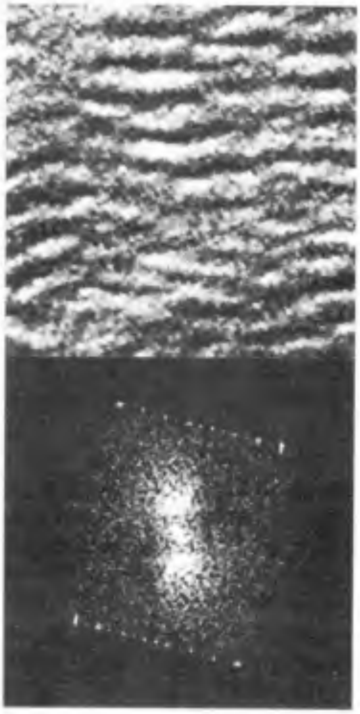

Fig. 6 Wave image & wave number spectrum at block S

From Table 1, we can see that the wavelength is decreasing and wave direction changes from 15° at block E to 350° at block S also. Fig.7 shows the variation of wavelength with wave direction from block E to block S.

Table 1 Results of water depth computation

Block	Wavelength	Wave direction 0° for N: clockwise	c/c_0	k	dp(m)	dr(m)
C	107	16	0.99	0.059	44	---
E	101	15	0.98	0.062	41	43
G	101	14	0.97	0.062	40	46
I	92	6	0.94	0.068	26	30
K	88	3	0.92	0.071	22	20
M	83	0	0.90	0.076	19	19
O	81	356	0.86	0.078	17	17
Q	75	353	0.83	0.083	14	15
S	68	350	0.80	0.092	12	10

Finally, the Snell's law of wave refraction and the small amplitude wave formula were used to compute the ratio of wave celerity from deep to shallow water and to predict the water depth at each block individually. Comparison of the predicted water depth (dp) and the measure's (dr) was also shown in Table 1 and Fig.8. The results are encourging.

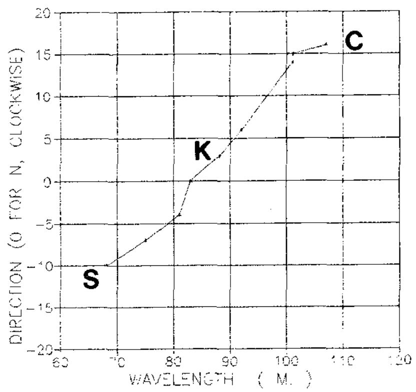

Fig. 7 Variation of wavelength with wave direction

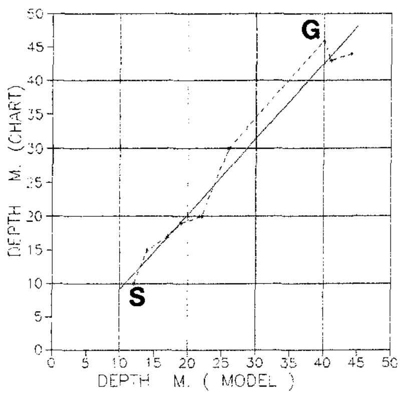

Fig. 8 Comparison of the predicted water depth and the measure's

Conclusions and Discussions

1. From the satellite image of the sea, we can get direct information of wave propagating from deep to shallow water, such as refraction, diffraction and reflection. It has the advantages of wide spatial information and lower coast, when compared to traditional field survey.

2. By combining Snell's law, dispersion relationship and spectral results, the bottom topography are easily derived. The results are encouraging.

3. The method used here takes the assumption of straight and paralled offshore contours; therefore the range of water depths can be estimated is within intermediate depth, i.e., from $L/2$ to $L/20$, where L is the wave length.

4. Block size influences the analyses. Larger block size provides better spectral resolution while causing more uncertainty due to shoaling effect. On the other hand, small block size has the problem of insufficient details. The present study uses a 128x128 pixel block size.

5. Effects of water color on the image may yield confusing in the detection of spectra. The top-hat transformation is used to reduce the influence of this factor.

6. SPOT Pan band images are used in the present spectral analyses. In comparison with most of the earlier works where SAR images were used, these images generally provides higher space resolution and lesser non-linear effects.

References

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