Bathymetric Ability of SPOT-5 Multi-spectral Image in Shallow Coastal Water

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Abstract—**Optical Remote Sensing offers an alternative to traditional hydrographic surveys for measuring water depth, with the advantage of low cost and large area. The multi-spectral image of SPOT-5 with the high resolution provides possibility for bathymetric mapping. In order to estimate the image's potential for the retrieval of water depth, we use single-band model and dual-band model separately to inverse the water depth with worked example from Naozhou Island in Guangdong, China. The actual depth is derived from the chart to establish inversion models and to assess the accuracy of inversed water depth based on the criterions of the mean relative error and the mean square error. The result illustrates that the dual-band model is superior to the single-band model and the red-band model is superior to the green-band model. Compared with the other segments of water depth, the mean relative errors in shallow water between 0m and 5m are the biggest, which make the overall errors of all models big. However, the dual-band model is relatively better than the single-band model in shallow water, its mean relative error is about 22%, and its mean square error is about 1.87m. We have a conclusion that the multi-spectral image of SPOT-5 has a good ability to inverse water depth, and its high resolution can describe more detail topographic information under water. Bathymetry by Remote Sensing becomes an important assistant means for traditional bathymetry methods.**

Keywords- Bathymetry; Remote Sensing; SPOT-5; Multi-spectral image[1]

I. INTRODUCTION

From the 20th century 60 years, the technique of Remote Sensing developed rapidly, which provided a new thought for bathymetry. Compared with the traditional methods of bathymetry, bathymetry by Remote Sensing has a lower precision, but it is low-cost, short-period and big-range. Therefore, it is suit for investigation and dynamic monitoring of seabed topography in shallow coastal water.

In the research of water depth inversion by satellite multi-spectral data, early in the 20th century, mid-to late 60s, researchers from Michigan Institute for Environmental Studies had started research work in this area, and had made significant contributions to the theory and the methods. Lyzenga(1978,1981) [1,2]、Benny(1983) [3]、Stove(1985) [4]、W. Ji(1992) [5] and Tripathi(2002) [6] established their inversion model separately, and carried out the experimentations based on different Remote Sensing data.

In China, Y. Zhang (1998) [7]、D. Zhang (1998) [8,9]、FX. Dang (2001,2003) [10,11]、JZ. Huang (2002) [12]、RX. Cao (2004) [13]、J. Fu (2006) [14] and QJ. Tian (2007) [15] successively used different satellite data to inverse water depth in different areas. During the period of Eighth Five-Year, MGMR used TM, SPOT, other satellite data and satellite altimeter data to investigate the water depth and seabed topography of China's Nansha Islands and adjacent waters with a small amount of field surveys. By improving the Remote Sensing model, the shallow water depth of Nansha reefs concentrated region was preliminarily identified, with the mean square error of 2.14m [16].

Overall, the statistical method is the main method of inversing water depth by Remote Sensing currently, the satellite images used are from Landsat-MSS, TM, ETM, SPOT-4, etc., and the mean relative errors are from 10% to 30%.

The bands of the visible light are effective to study the water depth and the underwater features. Compared with TM, the multi-spectral image of SPOT-5 lacks blue-ray, but its resolution is 10m, which is better than 30m of TM and 20m of SPOT-4, so it has advantages of detecting the detailed characteristics of underwater terrain. In this paper, we use single-band model and dual-band model separately to inverse the water depth with worked example from Naozhou Island, and assess the bathymetric ability of SPOT-5.

II. OPTICAL REMOTE SENSING INVERSION TECHNIQUE FOR WATER DEPHT

The physical basis of inversion by optical Remote Sensing is that the light can penetrate the shallow water in some extent. Among different wavelengths of electromagnetic wave, the visible band has the greatest atmospheric transmittance and the smallest water attenuation coefficient, so it is the best band for water depth inversion. When the water is clear enough, the sediment is relatively homogeneous, and the atmospheric conditions are good, the gray-scale of Remote Sensing images has a strong correlation with the water depth.

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The statistical method is the method for water depth inversion used most widely, which has the advantages of simple model and high precision, but it still requires to take a certain amount of measured depth data as control points. This method makes use of the relationship between Remote Sensing images pixel gray-scale and the measured water depth, and then inquires the unknown point of water depth. According to the quantity of bands used, the method is divided into single-band model, dual-band model and multi-band model. As SPOT-5 only has two visible bands of green and red, this article uses the first two methods only.

1) Single-band model

Clerk (1987) put forward a band algorithm model that is suitable for Landsat TM, and the basic expression is as follows:

$$L_i = L_{si} + C_i R_{bi} e^{-fk_i Z} \tag{1}$$

Where i mean band number, L_i is the radiance of the i band, L_{si} is the radiance of i band in deep water, C_i is a constant related with the solar irradiance, atmospheric and water transmittance and water surface refraction, R_{bi} is the substrate reflectance, k_i is the diffuse attenuation coefficient, f is the length of path of light transmission in water, and Z is the value of water depth.

The equation (1) can be transferred to the following:

$$Z = \ln(C_i R_{bi}) / fk_i - \ln(G_i - G_{si}) / fk_i \tag{2}$$

Assuming that the water and the seabed sediment reflectance are homogeneous, we can get the following equation:

$$Z = A_0 + A_1 X_\mathrm{i} \tag{3}$$

Where $X_i = \ln(L_i - L_{si})$, and A_0 and A_1 are the coefficients to be calculate.

2) Dual-band model

When the ratio of sediment reflectance has nothing to do with the change of sediment, we take the division operation for the two equations from single-band model, and the equation can be transferred to the following:

$$Z = [1 / f(k_2 - k_1)][\ln(\frac{C_1 R_{b1}}{C_2 R_{b2}}) - \ln(\frac{L_1 - L_{s1}}{L_2 - L_{s2}})] \tag{4}$$

The simplified expression is as follows:

$$Z = A_0 + A_1 X_1 + A_2 X_2 \tag{5}$$

III. METHOD

A. Study Area and Data

The surrounding water of Naozhou Island in Guangdong, China is chosen as the study area with the range of 40km × 26km. The island is located between Zhandong Port and Donghai Island, southeast of it is South China Sea, southwest is Hainan Province across Qiongzhou Strait, north is Donghai Island, and west is by Leizhou Bay.

The SPOT-5 multi-spectral image used WAS shot on November 3, 2006 with no cloud, shown in figure 1. The measured water depth data is from nautical chart with the scale of 1:40000, and was measured in 2002.

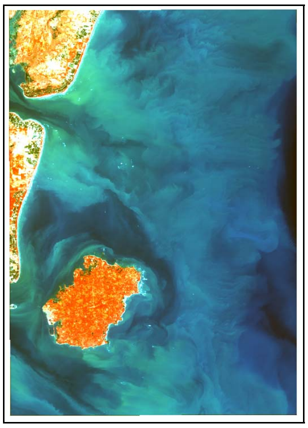


Figure 1. The Remote Sensing image of the study area

B. Data Preprocessing

1) Geometric correction for image and chart

To ensure the image and the chart in the same position on a strictly correspond, we use the ground control points measured by beacon GPS to correct the multi-spectral image with an error of less than two pixel, and take the points of intersection of latitude and longitude as controls to correct the chart that has been scanned. The corrected image and the corrected chart are well-matched at the same location with the same geographic coordinate system of WGS84.

2) Noise reduction and radiance calculation

The speckle noise exists on the original image, and should be reduced before use. The method of median filtering (3 × 3 template) is used for denoise in this paper. Not only it can reduce the noise, but also it can keep the details of the image and prevent the edge blurring.

The 1A-level data of SPOT-5 satellite is processed by radiometric correction primarily, in the procedure of which the pixel value quantified from 0 to 255. Through the calibration of radiation we can get the radiance of the surface features. The formula is as follows:

$$L = X/A + B \tag{6}$$

Where L is the radiance that the sensor received from the surface features, A is the absolute calibration-gain of the radiation-corrected image, and B is the calibration-bias of the image.

We can get that the parameter A is 1.829788 and B is 0 from the PHYSICAL_GAIN and PHYSICAL_BIAS labels in the metadata file. According to the formula above, the radiance of the image can be calculated.

3) Selection and tidal correction of the depth controls

The water depth inversion by Remote Sensing relies on a number of controls, which include the water depth and the gray value at the same place with the water depth point. The controls distribute as uniformly as possible not only throughout the study area, but also at different depth segments. We choose 82 controls (figure 2), the water depth of which ranges from 0.2m to 21.5m, and there are about 4 controls in the depth interval of 1m.

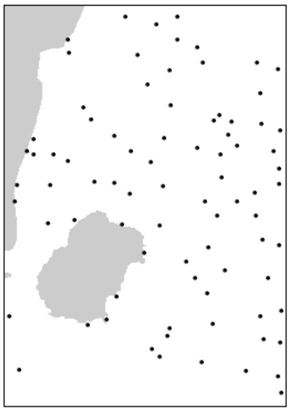


Figure 2. Distribution of the controls

The water depth from chart is calculated from the theoretical datum surface. Under normal circumstances, when the image is being shot, the value of the instantaneous water depth is bigger than that from chart influenced by tide. In the course of establishment of inversion models, we use the instantaneous water depth that is the depth from chart plus the tidal height.

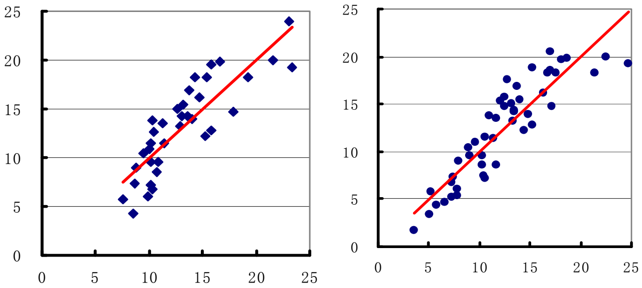
In virtue of the tide table in 2006, we calculate that the tidal height was 1.8m when the image was being shot. The sum of the depth from chart and the tidal height is used as the control depth for inversion. After inversion, we also should subtract the tidal height from the inversed value and obtain the actual water depth finally.

C. Depth Inversion

The coefficients of single-band model and dual-band model are respectively calculated based on the selected controls. In the process of calculation, we continuously remove the controls with large residual and optimize the inversion model under the precondition of ensuring the controls distributed in different depth segments. The inversion parameters is such as in table I, and the scatterplots of inversed values and measured values are shown in figure 3 (the horizontal axis denotes the inversed value, and the vertical axis denotes the measured value).

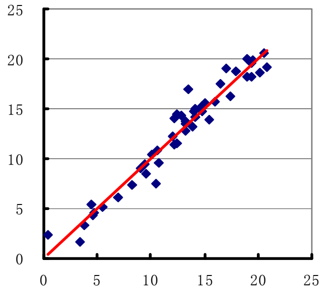
TABLE I. COEFFICIENTS OF INVERSION MODELS

Band	**Control quantity**	**A_0**	**A_1**	**A_2**	**Multiple correlation coefficient**
green	36	89.81	-61.79	\	0.72
red	48	48.64	-29.96	\	0.81
dual-band	48	-44.16	-67.59	110.67	0.95



a: green-band

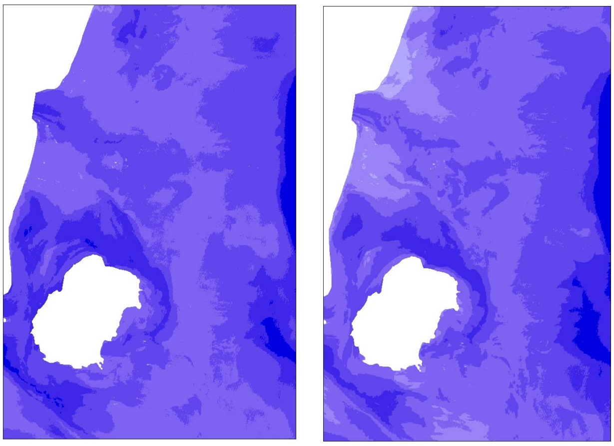
b: red-band



c: dual-band

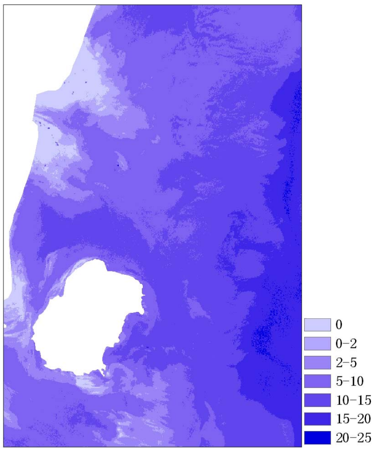
Figure 3. Scatterplot of inversed values and measured values

The operation of the inversion is performed in Model Builder of ERDAS. The inversed results of the three models minus the tidal height respectively are the actual water depth shown in figure 4.



a: green-band

b: red-band



c: dual-band

Figure 4. The result of water depth inversion

D. *Accuracy Assessment*

The mean relative error and mean square error are used to assess the inversion results, and the formulas are as follows:

Mean relative error: $$\overline{\delta} = \frac{\sum_{i=1}^{n} \Delta Z_i / Z_i}{n} \tag{7}$$

Mean square error: $$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (\Delta Z_i)^2}{n}} \tag{8}$$

Where $\triangle Z_i = | Z_i - Y_i |$, n is the quantity of the controls, Z_i is the measured value of the control, and Y_i is the inversed value of the control.

The checkpoints should be control-independent. We choose 39 checkpoints from the chart uniformly, note the measured value and the inversed value, and then calculate the mean relative error and mean square error. The results are shown in table II.

TABLE II. ERROR LIST OF INVERSED RESULT

Band	**Segments (m)**	**Mean relative error**			**Mean square error (m)**		
green	0-5	4.39	2.36	1.18	9.26	7.21	5.83
	5-10	0.55			4.68		
	10-15	0.27	0.27		3.72	4.47	
	15-20	0.28			5.02		
red	0-5	2.85	1.48	0.79	6.55	4.85	4.29
	5-10	0.25			2.50		
	10-15	0.31	0.25		3.85	3.81	
	15-20	0.21			3.78		
dual-band	0-5	0.51	0.34	0.22	1.57	1.61	1.87
	5-10	0.19			1.64		
	10-15	0.13	0.12		2.06	2.05	
	15-20	0.10			2.04		

E. *Results Analysis*

- In the process of inversed model calculation, we removed a large number of controls with large residuals. The residuals of the controls ranged from 0m to 5m are the biggest, and the controls are removed more than the other depth segments. Figure 3 shows that, the model of the green-band is the worst, that of the red-band is a little better, and that of the dual-band is the best. In terms of the multiple correlation coefficients of table I, the green-band is 0.72 and the red-band is 0.81. While the dual-band model is 0.95, and its fitting effect is superior to the single-band model.

- The inversed results (figure 4) of the green-band and the red-band have the similar trend of depth, but the green-band has almost no reaction to the shallow water. The other way round, the dual-band model has apparent response to the shallow water, and can keep more detailed features.

- According to the accuracy assessment results (table II), regardless of the mean relative error or the mean square error, the dual-band model is the best, followed by the red-band, and the green-band is the worst. The mean relative error of the depth segment from 0 to 5m is far larger than other depth segments. But with the increase of the water depth, the error is smaller and smaller. In the mass, for the single-band model, the mean square error of the shallow water is bigger than that of the deep water, but the dual-band model is contrary, and its mean square error is less than 2m only.

IV. CONCLUSION

Based on the multi-spectral image of SPOT-5 and the chart, we use single-band model and dual-band model separately to inverse the water depth with worked example from Naozhou Island, and then adopt the mean relative error and mean square error to assess the inversed accuracy. The main conclusions are as follows:

- The dual-band model is superior to the single-band model. For the single-band model, the red-band model is better than the green-band model.

- The mean relative error of the depth segment from 0m to 5m is the largest, and this makes the overall mean relative error of every model large, especially for the single-band model. So for the shallow water, the mean relative error can not be seen as the only criterion to assess the accuracy of inversion results.

- The dual-band model is the best of all the models used, its mean relative error is 22%, and its mean square error is 1.87m. The model worked relatively well for the shallow water.

The study is under the conditions that we assume the water to be clear and the sediment to be uniform, while the study area is located in the estuarine areas influenced seriously by the suspended solids, so water quality is not uniform and should lead to inversion errors. In addition, there is an interval of four years between the time of the image shot and the time of the chart measured, the depth from the chart could be different from the actual depth at the time of the image being shot, and this could cause errors too. If we could improve the timeliness of the measured data and improve the data processing methods to reduce the impact of suspended solids, the inversion accuracy should be better.

In short, the multi-spectral image of SPOT-5 has the ability to inverse water depth, and its high resolution can describe more detail topographic information under water. Though bathymetry by Remote Sensing can not be instead of the traditional survey methods, but it has become an important assistant means. With the development of high spatial and high spectral resolution Remote Sensing technology, bathymetry by Remote Sensing will have a good application prospect.

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