CHINESE GEOGRAPHICAL SCIENCE
Volume 14, Number 3, pp. 258–262, 2004
Science Press, Beijing, China

SHALLOW SEAWATER DEPTH RETRIEVAL BASED ON BOTTOM CLASSIFICATION FROM REMOTE SENSING IMAGERY

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ABSTRACT: Remote sensing technique, replacing conventional sonar bathymetry technique, has become an effective complementary method of mapping submarine terrain where special conditions make the sonar technique difficult to be carried out. At the same time, as one kind of data set, multispectral remote sensing data has the disadvantage of being influenced by the variable bottom types in shallow seawater, when it is applied in bathymetry. This paper puts forward a new method to extract water depth information from multispectral data, considering the bottom classification and the true water depth accuracy. That is the Principal Component Analysis (PCA) technique based on the bottom classification. By the least square regression with significance, the experiment near Qingdao City has obtained more satisfactory bathymetry accuracy than that of the traditional single-band method, with the mean absolute error about 2.57m.

KEY WORDS: multispectral remote sensing; bathymetry model; PCA; bottom classification

CLC number: TP79 Document code: A Article ID: 1002-0063(2004)03-0258-05

1 INTRODUCTION

Submarine terrain in shallow sea is one of important factors of the ocean environment, and has important meanings for coastal economics and military activities. For the mapping of the vast offshore marine terrain, a traditional ship-borne sonar bathymetry system is often restricted by the special areas. However, remote sensing technique, as a complementary method, has an advantage of mapping the submarine terrain in vast shallow seawater areas rapidly. Among the techniques of satellite-borne remote sensing bathymetry, multispectral data is one of data sources most in use.

As for the research on the methods of passive multispectral bathymetry, PHILPOT (1989) pointed out that it is difficult to compute the true water depth with some simple bathymetry models and single spectral analysis, because of varied water types and bottom types; and MOREL and LINDELL (1998) computed the true water depths, using TM imagery to estimate the coefficients of bathymetry model, and then corrected it with sonar data.

At the same time, many researches (SERWAN and BABAN, 1993; MARITORENA, 1996; LYZENGA, 1981, 1985) have been done on the methods of remote sensing bathymetry. But, most of the studies did not consider the influence from the diversity of bottom types, and extracted the water depths information using the ordinary methods of single-band and multi-band linearity regression.

Based on the above, this paper will put forward a new method, Principal Component Analysis (PCA) based on bottom classification, to retrieve the true water depth information, and take the TM imagery of offshore sea area in Qingdao City, Shandong Province as an example to verify the theory.

2 BOTTOM CLASSIFICATION MODEL OF REMOTE SENSING BATHYMETRY

There are varied bottom types in the shallow seawater area, therefore, the reflection features of the bottom

Received date: 2004-04-07
Foundation item: Under the auspices of Scientific Foundation Research Project of the Ministry of Science and Technology and Chinese Academy of Surveying and Mapping (No. F0610)
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types are different in the visible bands. Under the condition of appropriate water bodies and after radiation correction, the distinct influence factors on the remote sensing bathymetry are the bottom types and the accuracy of the true water depth data. The discrepancy of the bottom types has influence on the gray degrees in the remote sensing imagery directly, for example, light sand bottom make the gray value of image bigger than the practical radiation, while algae and mud bottom can make it smaller than it will be in nature.

As the precondition of the bottom classification, it is assumed that the ratio of water attenuation coefficients between the studied imagery bands is a constant. According to SPITZER and DIRKS (1987) before deciding the ratio and computing the codes of bottom types, the appropriate study bands should be decided firstly to distinguish bottom types. So, we should make the scatter points plot between every two bands, and compare the linearity relations between X_i and X_j, where X_i is the gray value of band i, X_j is the gray value of band j, compute all the possible ratios of water attenuation coefficients. Contrary to the complicated process, this paper adopt a new method to decide the two optimum bands rapidly, thus to classify the bottom types and compute the corresponding bottom types codes.

According to the water depth retrieval model of remote sensing bathymetry, after the deep-water radiation correction, the imagery gray value X_i will decrease to a new value, that is, $X_i=(Ls_i-Lsw_i)$, which has a linear relationship with the true water depth Z as follows:

$$Z=-\frac{\ln(Ls_i-Lsw_i)}{K_i}+\ln(Lb_i-Lw_i) \tag{1}$$

where Ls_i represents the nadir radiation value acquired by band i from the top of the atmosphere; Lsw_i, deep-water radiation value, a constant; Lw_i, water body back scatter radiation value; Lb_i, water bottom radiation value; K_i, the water attenuation coefficient.

Thus, if we figure out the three dimension scatter points plot of X_i (i=1, 2, 3), setting $X_i=(Ls_i-Lsw_i)$, we can find that the projection data of different bottom types data clouds on the three coordinate faces present linear correlation, with the slope value just being K_j/K_i, where K_j represents the the water attenuation coefficient of band j, and being parallel with different distance lines each other.

This paper, firstly, selects Landsat TM1 band as a base band, and after the image pre-processing, then makes unsupervised classification to obtain the basic classification types. In order to reduce the errors, we take the type with the maximum image data as the study target, compute the three projection data on the coordinate face, and come into being the scatter points plots of X_i and X_j between every two bands in TM band 1, band 2, band 3, respectively. So that, we can analyze the projection data clouds using the least square regression, and choose the two bands, with which we can obtain the minimum linear regression errors, as the resultant bands to decide the water bottom types. Then we have the following formulae from the linear regression:

$$K_j/K_i=\frac{a}{\sqrt{1+a^2}} \tag{2}$$

$$a=\frac{\sigma_{ii}-\sigma_{jj}}{2\sigma_{ij}} \tag{3}$$

where, σ_{ii} is the variance of X_i, σ_{jj} is the variance of X_j, and σ_{ij} is the covariance of X_i and X_j.

For different bottom types, we can measure the different distances between the parallel lines and those through the origin, to distinguish the reflection discrepancies between different bottom types, and the expression to compute distances is as follows:

$$Y_i=\frac{K_j\ln(Ls_i-Lsw_i)-K_i\ln(Ls_j-Lsw_j)}{\sqrt{K_i^2+K_j^2}} \tag{4}$$

where Y_i represents the bottom type code based on band i, Ls_j and Lsw_j are the gray value and deep-water radiation value of band j, respectively. So that, the bottom types codes may be computed as the formulae:

$$Y_i=C_1X_i+C_2X_j \tag{5}$$

$$C_1=\frac{K_j/K_i}{\sqrt{1+(K_j/K_i)^2}} \tag{6}$$

$$C_2=\frac{1}{\sqrt{1+(K_j/K_i)^2}} \tag{7}$$

where C_1 and C_2 are the statistical coefficients to compute water bottom type code.

Thus, the Y_i value of every point on the remote sensing image can be computed out by special procedure, and be treated as a constant for a special bottom type, which has no relation with the variance of water depth. The bottom types map eliminating the influence from the water depths can also be produced according to it.

3 WATER DEPTH RETRIEVAL FROM REMOTE SENSING IMAGERY

To eliminate the influence on the reflection spectral values from the discrepancies of the bottom types, and decreased the error from the true water depth points accuracy, this paper, taking the principal component image (PC1) as the study data, according to the codes of the bottom classification, and using the least square method, retrieves the linear coefficients of each bottom type. So, we can acquire the true water depth and establish the continuous pixel-to-pixel remote sensing bathymetry images. The basic technique flow chart is shown in Fig. 1.

3. 1 Bottom Classification Processing

Before classifying the water bottom types, we firstly do some preprocessing, such as image radiation rectification, precisely geometry rectification, separation of water and land area, filtering, segment linear extension, and so on. After all the preprocessing works have been done, we can compute the code of each bottom type point to point, according to the above theory.

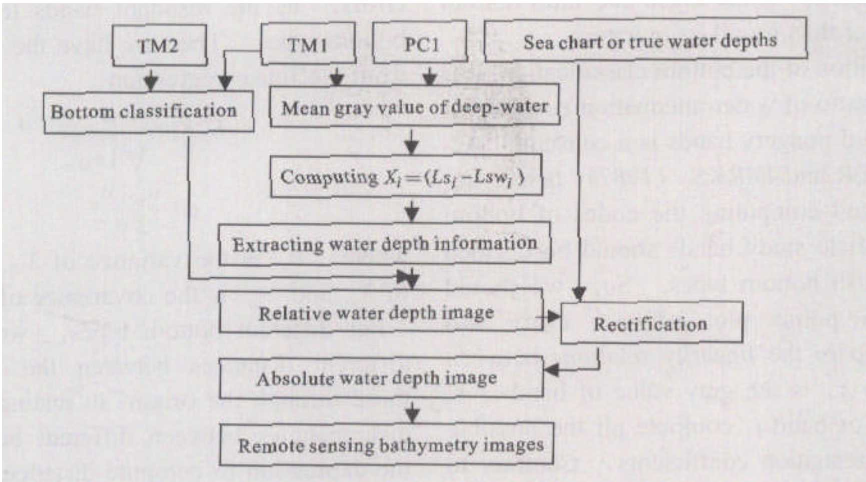

Fig. 1 Water depth information extraction flow chart from TM images

Correspondingly, we must do the following specific works: 1) compute the X_i value of each pixel of the image; 2) acquire the bottom type with maximum imagery data using unsupervised classification; 3) make out the scatter points plots of X_i, and X_j, and analyze the linear relations between them; 4) compute the water attenuation coefficients of the two optimum bands; 5) compute the code of bottom type for each point; 6) output the bottom classification map.

3. 2 PCA Processing

For the multispectral images of shallow seawater, it is assumed that the change information of radiation spectra from water is mostly derived from the change of the true water depths, and the sequent parts are derived from the diversity of the offshore water bottom types. So the bands of TM1, 2, 3 can be processed with PCA model to compute out the three principal components data, comprising of PC1, PC2, and PC3 images, respectively. The three image data are perpendicular each other, and have no relations each other in space. At the same time, in the group of PC1 and PC2, or PC2 and PC3, the latter always has the maximum data part, which is perpendicular to and smaller than the former, representing less change information. To extract the water depth information having nothing to do with bottom types, we treat the PC1 image data as the studied image.

3.3 Regression Analysis Based on Bottom Classification

Normally, the true water depths under the condition of different bottom types have different relations with X_i. Based on the bottom classification codes, we can classify the true water depths into groups, and respectively estimate the weight of each water depth point in the same bottom type. For example, we can integrate the variance of the true water depths with other factors, to decide the weight of each water depth point. And, the lower the accuracy of the true water depths is, the bigger the variance is, also the smaller the weight is. Then, we utilize weighting least square regression to compute out the corresponding linear coefficients, a_i and b_i, under the condition of the same bottom type. The computation formula is as follows:

$$Z_{ij}=a_iX_{ij}+b_i,\ P_{ij}\ \text{(weight matrix)}\ \ i,j=1,2,3... \qquad (8)$$

where Z_{ij} is the true water depth value of bottom i, and water rectification point j; X_{ij} is the X value of bottom i, and water rectification point j, $X=\ln(Ls-Lsw)$; P_{ij} is the weight of bottom i, and water rectification point j.

At last, we compute the bottom type code for each pixel, using formula (1) to obtain the last absolute water depth to establish the corresponding water depth remote sensing images, and estimate the relative remote sensing bathymetry accuracy.

4 TEST RESULTS AND ACCURACY ANALYSES

According to all of the above, this paper chose the Landsat TM images near Qingdao City, in 1998, as the study data set. After the preprocessing, we obtained the PC1 image (Fig. 2), and the bottom types codes map (Fig. 3). Then, using 15 true water depth points, which are obtained from sea chart, we analyzed the linear relations between them and the corresponding X_i values, and found that the absolute value of the negative linear relation coefficient (−0.493425) is smaller than that derived from bottom classification. For example, the coefficients are −0.665720 and −0.850439 for bottom 1 and bottom 2, respectively, based on bottom classification.

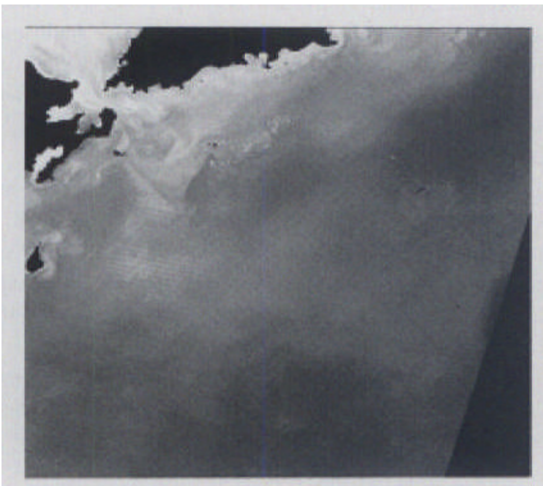

Fig. 2 PC1 image extracted from TM1, 2, 3

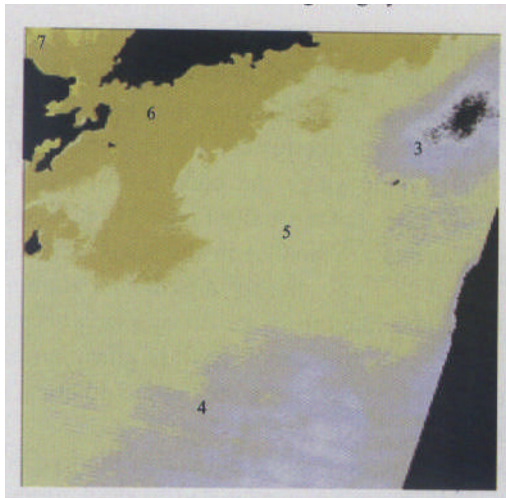

Fig. 3 Bottom classification codes

Aiming to compare the bathymetry accuracy with that of traditional single-band remote sensing bathymetry, we analyzed the accuracy of the results from PCA method based on bottom classification, and obtained the false results from the two study methods (Table 1) and the last water depth remote sensing images (Fig. 4).

From the resultant images of the above, we can find that the absolute error at the same water depth point

Table 1 Error analysis of two remote sensing bathymetry methods

Method	Linear coefficient a	Linear coefficient b	Mean absolute error (m)
PCA			
Bottom Ⅰ	−20.3416	116.7681	0.9501
Bottom Ⅱ	−47.8349	258.4059	4.1915
Bottom Ⅲ	−63.1818	241.7499	0.0121
Average			2.5728
Single-band	−7.3411	58.8454	6.0089

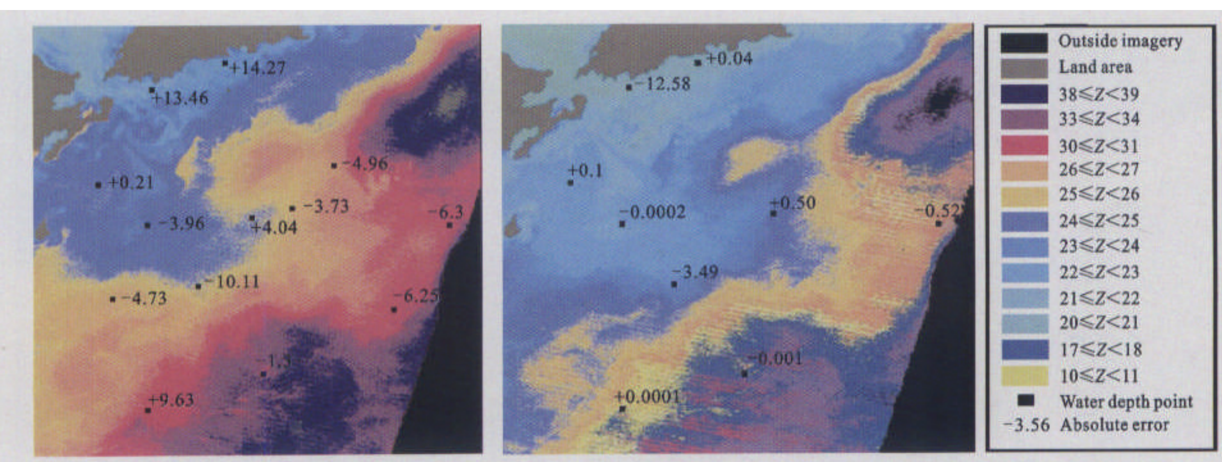

Fig. 4 Water depth images extracted from single-band (the left one) and from PCA method (the right one)

derived from PCA method based on bottom classification is smaller than the that computed from single-band method. And the corresponding water depth levels are denser. In the results, the computing error at water depth point where the code is 5, with water depth value 22m, is the smallest one. The whole absolute depth errors are smaller in the water depth scope from 22m to 28.75m. For the area with a bottom type code 4, the absolute errors are dissatisfying because of the scarcity of the true water depth rectification points. But this can be improved by adding the practical rectification points.

What is should be pointed out is that the true bottom classification types are not labeled in the bottom classification codes map, considering that it weakly influences on the extracting of water depth information.

Through the experiment, we can obtain the conclusion as follows:

(1) Bottom classification has an important effect on passive multispectral bathymetry in shallow seawater.

(2) Using PCA technique to extract water depth information can obtain higher accuracy than single-band method, as utilizing more bands images information.

5 ERROR SOURCES ANALYSES

For the passive multispectral remote sensing bathymetry technique, the TM data is often influenced by the atmosphere conditions and water body lucidity. The errors in the experiment are primarily derived from the two aspects. Firstly, the inequality of the bottom types makes the corresponding image values bigger or smaller than the true ones. It is possible that one bottom type intermingles with the other ones, so that the reflection values are often the mean value from more than one bottom types. Secondly, the distribution and accuracy of true water depth points are one of the errors sources.

In addition, the rectification scale of the used sea chart is 1: 2 000 000, and the true water depth points are sparsely distributed, as a result, there are less data of true water depth after bottom classification. All of these cause the reduction of the remote sensing bathymetry accuracy ultimately.

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