PCA BASED ON BOTTOM CLASSIFICATION APPLIED IN REMOTE SENSING BATHYMETRY OF SHALLOW SEAWATER

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ABSTRACT:

The submarine terrain in shallow sea is one of the important factors of the ocean environment, and has important meanings for coastal economics and military activities. For the mapping of the vast inshore marine terrain the traditional ship-borne sonar bathymetry system is often restricted by the special areas. However remote sensing technique, as an effectively complementary method, has an advantage of mapping the submarine terrain in the vast shallow seawater areas rapidly. Among the technique of satellite-borne remote sensing bathymetry, multi-spectral data is one of important data sources in use. This paper puts forward a new method, Principal Component Analysis (PCA) based on bottom classification to extract the water depth information from multi-spectral data, considering bottom classification and practical depth accuracy. And, it takes the TM imagery of inshore sea area in QingDao city ShanDong province in China as an example to verify the theory. Practical water depth information is retrieved utilizing least square estimate with adding weights, and tested by practical data. The test result is more satisfactory than traditional method, with the mean absolute error about 2.57m.

INTRODUCTION

Remote sensing technique, as a complementary method of surveying submarine terrain, has an advantage of mapping the submarine terrain in vast shallow seawater areas rapidly. Multi-spectral data is one of data sources mostly in use.

As for the research on the methods of passive multi-spectral, PHILPOT(1989) pointed out it is difficult to compute the practice water depth with some simple bathymetry models and only spectral analysis, because of the varied water and bottom types, and MOREL and LINDELL (1998) had researched it too. But most of studies did not consider the influence from the diversity of bottom types, and extracted the water depth information using the ordinary method such as single-band or multi-band linearity regression.

Based on the above, this paper put forward a new method, that is principal component analysis (PCA) based on bottom classification, to retrieve the true water depth information, and took the TM imagery of near shore sea area in QingDao city, Shandong province, in China as an example to verify the theory.

1. BOTTOM CLASSIFICATION MODEL OF REMOTE SENSING BATHYMETRY

There are varied bottom types in the shallow seawater area, and the reflection features of the bottom types are different in the visible bands. Under the condition of appropriate water bodies and radiation correction, the distinct influence on remote sensing bathymetry is water bottom type and the accuracy of practical water depth data. The discrepancy of the bottom types has influence on the grey degree in the image directly. For example, light sand bottom will make the grey value of image bigger than the practical radiation, while algae or mud bottom makes it smaller than it will be in true. So in shallow water remote sensing bathymetry, the discrepancy of bottom types becomes an important influence factor.

As the precondition of the bottom type classification, it is assume that the ratio of water attenuation coefficients between the studying imagery bands is a constant. According to 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 two bands and compare the linearity relations between X_i and X_j, compute all the possible ratio of water attenuation coefficients. Contrary to the complicated processing, this paper adopted 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 water depth retrieval model of remote sensing bathymetry, after deep-water radiation correction, the imagery grey value X_i has a linear relationship with the true water depth Z just as follows:

$$Z = -\frac{\ln(L_{si} - L_{swi})}{K_i} + \ln(L_{Bi} - L_{Wi}) \qquad (1)$$

Where L_{si} represents the nadir radiation value acquired by band i from the top of atmosphere; L_{swi} is the deep-water radiation value, a constant; L_{wi}, water body back scatter radiation value; L_{bi}, water bottom radiation value; and K_i is the water attenuation coefficient.

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

This paper firstly selects TM1 band as the basic one, after the image pre-processing, then uses unsupervised classification to obtain the basic classification types, in order to reduce the error, we take the types with the maximum image data as the study target, compute the projection data on the coordination face, come into being the scatter points plot of X_i and X_j between every two bands in TM band 1, 2 and 3 respectively, so that we can analyze the projection data clouds using the least square regression errors ,as the resultant bands to decide the water bottom types, then we have the following formula 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 covariance of X_j , σ_{ij} is the covariance of X_i and X_j. For different bottom types, we can measure the different distance between the parallel lines and those through the origin, to distinguish the reflection discrepancies between different bottom types and the expression to computer distance 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; L_{Si} and L_{Swi} Are the grey value and deep-water radiation value of band j respectively, so that the bottom codes may be computed as the formula:

$$Y_i = C_1 X_i + C_2 X_j \tag{5}$$

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

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

Where, C_1 and C_2 are the statistical coefficients to computer water bottom type code.

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

2. ECTRACTING WATER DEPTH INFORMATION FROM REMOTE SENSING IMAGERY

2.1 Bottom Reflection Model Based on Remote Sensing Bathymetry

The whole Radiation quantity received from the sensor is divided into five parts as follows, according to the theory of bottom reflection researched by many researchers:

$L_{\text{sensor}} = L_{\text{sun light reflection from water surface}} + L_{\text{reflection from water bottom}} + L_{\text{back reflection from water body}} + L_{\text{back reflection from heaven light}} + L_{\text{heaven light reflection from water surface}}$, which can be replaced by:

$$\begin{aligned} L_s &= L \ + L_a + L_g \\ &= L_W \left[1 - \exp(-KZ)\right] + L_B \exp(-KZ) + L_a + L_g \end{aligned} \tag{8}$$

Where, L is the same meaning as the forgoing one; La is the atmosphere back reflection; Lg represents the reflection of sun and heaven light from water surface; Ls is the nadir reflection received by the sensor on the top atmosphere, so we can obtain as follows from formula (8):

$$L_s = L_W + L_a + L_g + (L_B - L_W)\exp(-KZ) \tag{9}$$

then, we have:

$$L_s - (L_W + L_a + L_g) = (L_B - L_W)\exp(-KZ) \tag{10}$$

if setting L_W+La+Lg=Lsw, where Lsw represents the deep-water reflection value, then we can make logarithm on both sides of it and obtain the formula (11):

$$\ln(L_s - L_{SW}) = \ln(L_B - L_W) - KZ \tag{11}$$

so, the formula (12) can be easily deduced as follows:

$$Z = \frac{\ln(L_s - L_{SW})}{K} + \ln(L_B - L_W) \tag{12}$$

if we let: a=-1/K，b= ln(L_B-L_W)， X= ln(Ls-Lsw), then the model of bathymetry remote sensing information can be simplified as formula (13):

$$Z = aX + b \tag{13}$$

2.2 Method of Data Processing

for a remote sensing image of shallow seawater, the primary varied information of water reflection spectral is considered to derived from the changing of water depth , and secondly from the different water bottom types in near shore seawater. In this paper, we take TM band1, TM band2 and TM band3 as the source dataset to make the model analyses of primary component analysis (PCA), compute out the three offset data from them to form the image files as PC1, PC2 and PC3 respectively. As we all known, the spatial relationships among the three dataset are perpendicular each other, and not correlative. The later one always involves the maximum section data which are upright to the former offset data, and represent the varied information less than it. Thus, to extract the water information which is not correlative with the bottom types, we can regard PC1 image extracting from three bands as the bathymetry information imagery, and the data source for extracting the water depth information through PCA algorithm.

Next, combining with bottom type classification image map, we can compute the relative bathymetry remote sensing image, and through correcting with sea map data or practical water depth value, form the absolute water depth remote sensing image eventually.

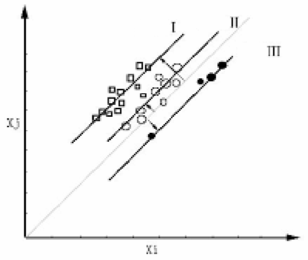
This paper based on the weighted least square estimate, to compute the absolute water depth value, which can improve the bathymetry precision, and verified in the experiment with remote sensing images of QingDao city, Shandong province in China.

Firstly, the water depth remote sensing image is processed with bottom type classification to acquire the corresponding bottom classification code, which can be described in detail as follows:

- Compute part pixel value of deep-water.
- Compute X_i value of each pixel.
- Make scatter plot with band couple, and compare the linear relation between X_i and X_j to make sure the researched bottom area.
- Compute all the water attenuation coefficient ratios as soon as possible.
- Select the band for distinguishing bottom type.
- Decide the ratio of water attenuation, and compute the water body bottom type code pixel by pixel.
- Export the bottom type map.

Secondly, we can divide the practical water depth values into several groups according to their bottom types, and under the condition of the same bottom type, judge and compute the corresponding weight for each practical water depth value. Owing to the different precision the practical water depth values will have different contribution on the same regress model. According to the practical condition, we can integrate variance with the other factors to evaluate the corresponding weight for each practical water depth. Commonly, a linear relationship exists between practical water depth with the same bottom and the X_i values, and on the contrary, it is different for different bottom types.

Further more, the same bottom type and grey value will be against to the approximately equal water depth value. The bigger is the variance, the more fluctuate for error contribution is. The worse is the precision, the less contribution for computing of bottom type is, and smaller corresponding weight. Otherwise, it will be bigger than that.



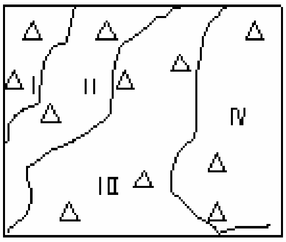


Fig.1 the relationship between Ki/Kj and bottom types (the left one) Fig.2 the practical water depth points and bottom types (the right one, △:practical water depth point; Ⅰ、Ⅱ、Ⅲ、Ⅳ:bottom types)

For various bottom types, we adopt the least square estimate with weight respectively, so that to compute out the corresponding linear coefficients a_i and b_i, and the computing formula is as follows:

$$Z_{ij} = a_i \cdot X_{ij} + b_i \; ; \; P_{ij}(\text{weight})$$

(i= Ⅰ, Ⅱ, Ⅲ, Ⅳ …..bottom types; j=1,2,3,…..) (14)

where ,Z_{ij} is the practical water depth value of bottom type i and corresponding point j; X_{ij} is the X value of bottom type i and correcting point j; X=ln(Ls-Lsw); P_{ij} is the weight value of bottom type i and corresponding point j.

In order to gain the linear coefficients for each corresponding bottom type, it needs to compute as the condition formula:

$$(a \cdot X + b - Z)^T \cdot P \cdot (a \cdot X + b - Z) = \min \quad (15)$$

Where, X, P, Z is the corresponding matrix respectively for all the practical water depth points and the grey values derived from different bottom types.

So, using special software to judge the bottom type code for each pixel point, the linear coefficient matrix will be computed out, according to the theory of adjustment computing. Certainly, the bathymetry relative and absolute precision can be computed out finally.

3. TEST AND RESULT ANALYSIS

This paper is based on all the above theory. Choosing the LandSat TM image near QingDao city as the data source, after pre-processing, we obtained the PC1 image (shown as Fig.3), and the bottom classification codes map. Then, using 15 practical 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 values of 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.

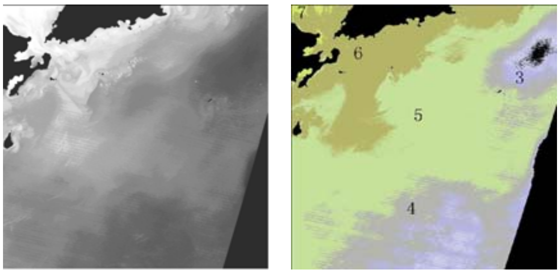


Fig.3 PC1 image extracting from TM1、2、3(the left one) and bottom classification codes map(the right one)

Aiming to compare the bathymetry accuracy with that of tradition single-band remote sensing bathymetry, we analyzed the accuracy of the results from PCA method based on bottom classification, and obtained the error results from the two study methods (shown as Table 1) and the last water depth remote sensing images (Fig.4 and Fig.5).

Table 1 the error analysis of the two remote sensing bathymetry methods

Method	Bottom type	linear coefficient a	Linear coefficient b	mean absolute error(m)
PCA	Ⅰ	-20.3416	116.7681	0.9501
	Ⅱ	-47.8349	258.4059	4.1915
	Ⅲ	-63.1818	241.7499	0.0121
	average :2.5728m			
Single-band		-7.3411	58.8454	6.0089

From the above resultant images, we can find the absolute error at the same water depth point 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, the computer errors at water depth point where the code is 5, water depth values 22m, is the smallest one. The whole absolute error in the water depth is smaller with a scope from 22m to 28.75m for the area of bottom type code is 4, because of the scarcity of practical water depth rectification points, but this can be improved by adding the practical rectification points.

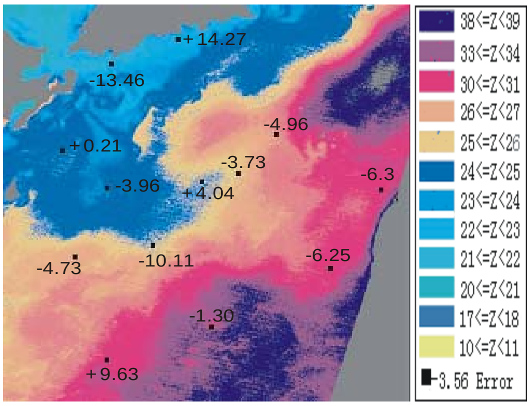


Fig. 4 the 1m water depth image extracting from single-band

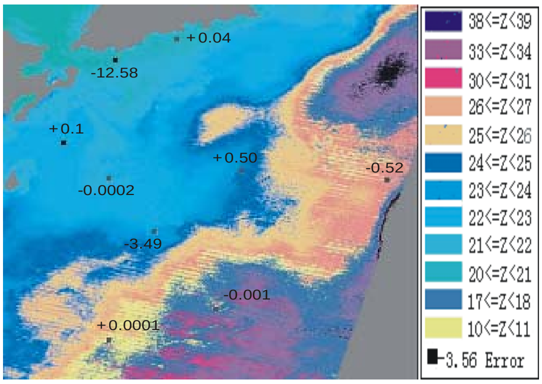


Fig.5 the 1m water depth image extracting from PCA

Where should be pay attention to is that bathymetry result image is not evident for the type name of true water bottom are not be marked on the bottom type codes map.

4. CONCLUSION

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

- Bottom type classification plays an important role in remote sensing bathymetry, even in water information retrieving from passive optical remote sensing image.
- The precision of PCA method based on bottom type classification, due to adopted multi-spectral image information, is better than single-band method.

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