Bathymetric mapping in Dong-Sha Atoll using SPOT data

Shih-Jen Huang and Yao-Chung Wen
Department of Marine Environmental Informatics, National Taiwan Ocean University, Keelung, 202, Taiwan

ABSTRACT The remote sensing data can be used to calculate the water depth especially in the clear and shallow water area. In this study, the SPOT data was used for bathymetric mapping in Dong-Sha atoll, located in northern South China Sea. The in situ sea depth was collected by echo sounder as well. A global positioning system was employed to locate the accurate sampling points for sea depth. An empirical model between measurement sea depth and band digital count was determined and based on least squares regression analysis. Both non-classification and unsupervised classification were used in this study. The results show that the standard error is less than 0.9m for non-classification. Besides, the 10% error related to the measurement water depth can be satisfied for more than 85% in situ data points. Otherwise, the 10% relative error can reach more than 97%, 69%, and 51% data points at class 4, 5, and 6 respectively if supervised classification is applied. Meanwhile, we also find that the unsupervised classification can get more accuracy to estimate water depth with standard error less than 0.63, 0.93, and 0.68m at class 4, 5, and 6 respectively.

KEY WORDS: SPOT, Dong-Sha atoll, bathymetry, unsupervised classification

1 INTRODUCTION

Reflection, scattering and absorption are the physical processes which happen if an electromagnetic wave passes through the particle in its path. Such as, grass looks green because it scatters green light while it absorbs red and blue light. Remote sensing involves the interpretation and inversion of radiometric measurements of electromagnetic radiation measured some distance away, where the radiation is characterized by a specific wavelength that is sensitive to some physical aspect of the medium. In visible band, the shorter wavelength light penetrates water further than longer one (Blyth, 1981). Estimating water depth using remotely sensed data depends on the amount of reflected radiance, which is affected by water clarity, depth attenuation, bottom reflectance, scattered suspended material and so on.

In the clear open ocean, the transmittance approaches 60% during the wavelength 0.4~0.6μm (Gross, 1992). On the account of selective absorption, water acts essentially as a monochromator of blue light; an absorption maximum occurs at near infrared (Jerlov, 1951). Several articles have successfully demonstrated the use of airborne or satellite remote sensing data for estimation of depth of water in lakes and seas (Lafon et al., 2002; Islam et al., 2004; Leu et al., 1999; Irish and Lillycrop, 1999). In 2002, Tripathi and Rao maps the bathymetric in Kakinada bay by using visible band image.

Dong-Sha Atoll near, (21°N, 117°E), is the study area in this research. It will be the Dong-Sha Marine National Park in the future. Its bottom is composed of coral, sand, sand with seagrass or coral with algae etc. (Liu et al., 2005). Dong-Sha Island (Pratas Island), the largest Island in South China Sea, is located at northwest corner of Dong-Sha Atoll.

The SPOT image data is used in this study. Single band model is applied to retrieve the depth of water while the SPOT blue band data and the in-situ measured are used. The tidal data is collected for water depth correction. This study uses different regression equations to estimate the water depth according to the classification types which are categorized by the unsupervised classification.

2 DATA

2.1 Satellite Image

The SPOT image is provided by Center for Space and Remote Sensing Research (CSRSR) National Central University. Its image ID is I0008831, which was acquired on 5/23/2003. This image has 2200 lines and 3000 samples. Its resolution is 10m. Figure 1 shows the SPOT image of Dong-Sha Atoll. Its center is located at (20.6820382°N, 116.8031718°E).

2.2 In-situ water depth

About one thousand in-situ data are collected in this study. The in-situ water depth data is collected by Color Video Plotter GD-1900C which has echo sounder to measure water depth and GPS to locate the sampling point. The in-situ water depth is measured from 8 courses, and each sampling point has 15" interval along longitude. After matching with the SPOT image of clear sky, 868

in-situ data can be available in this study.

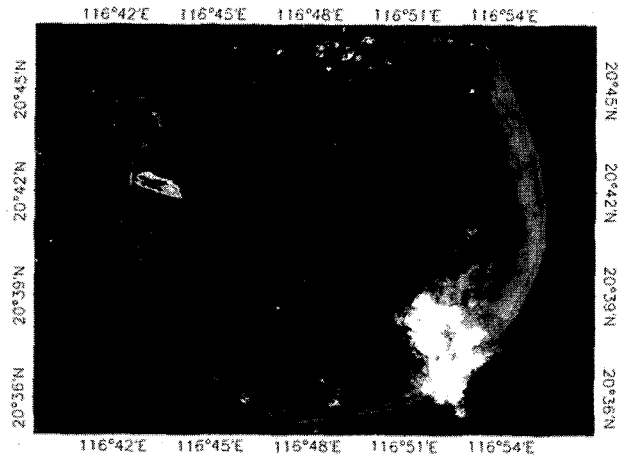

Figure 1. The SPOT image of Dong-Sha atoll on 5/23/2005.

3 METHOD

Under the assumption of homogeneous atmosphere, similar wave situation, similar water property, and homogeneous bottom property, the water depth can be retrieved from satellite data. The satellite sensor detects that the visible light penetrates water column, then it is reflected from the water bottom, and back through water column to the sensor. Doak et al. (1979) found the relation model of water depth and satellite data as

$$P_{SN} = P_{AN} + P_{DN} \exp(-2KZ) \quad (1)$$

where P_{SN} is the radiance observed at the satellite sensor; P_{AN} is the deep-water radiance; P_{DN} is the radiance of exposed bottom material; Z refers to water depth; K is the effective water attenuation coefficient.

After natural logarithmic transformation, Eq.(1) takes the following linear form:

$$Z = -\frac{1}{2K}\ln\left(\frac{P_{SN} - P_{AN}}{P_{DN}}\right) \quad (2)$$

since the water depth (Z) corresponds with $\ln\left(\frac{P_{SN} - P_{AN}}{P_{DN}}\right)$, we can get a linear regression equation as

$$Y = aX + b \quad (3)$$

Where Y presents the water depth, X refers the $\ln\left(\frac{P_{SN} - P_{AN}}{P_{DN}}\right)$; a and b are the regression coefficients.

4 RESULT AND DISCUSSION

Before calculating of the water depth, the land and cloudy area need masking. The in-situ measurement data is used to validate the retrieved water depth from the clear-sky image data. Because the water depth model is the shallow water one, the major study would be focused on the inner and upper areas of Dong-Sha Atoll.

4.1 Non-classification

The in-situ data through tidal correction is randomly selected into two sets. One is for regression, and the other is for validation. After the regression data set of the in-situ and the satellite data are put into the Eq.(3), the regression function is found as,

$$Y = -4.7298X + 20.881 \quad (4)$$

The coefficient of determination (R^2) is 0.95 for the regression data set. Meanwhile, Figure 2 shows R^2=0.95 for the validation data set. Table 1 shows 87.6% data points of the regression data set have ±10% error in case of non-classification. Besides, when the error is ±20%, the data points will reach 90.6%. In the case of validation data set, there are 84.6% data points whose error is less than ±10%. Meanwhile, when the error less ±20%, the data points will reach 90.7%(table 2).

4.2 Classification

In this study, the unsupervised classification is used to categorize the SPOT image into 10 classes. The result shows all the data points can be classified. Class 1, 2 and 3 have no data. Class 4 owns the most data points, about 60.2%. Class 5 and class 6 have 19.7% and 7.6% data points respectively. The rest classes, 7 to 10, own 12.5% data points. Those classes represent shoal, land and cloud cover area according to the near infrared image and in-situ measurement. Therefore, only classes 4, 5, and 6 will be discussed in this study.

The in-situ data through tidal correction is randomly selected into two sets. One is for regression, and the other is for validation. In class 4, the regression data set and satellite data can get the regression function as

$$Y = -3.9662X + 19.835 \quad (5)$$

The R^2=0.92 for the regression data set. Figure 3a shows R2=0.88 for the validation data set. Table 1 shows 88.7% data points of the regression data set have ±5% error. Moreover, the error of data points is less than ±10%. The result of validation data set with Eq.(5) shows 84.4% data points have ±5% error. There are 97.7% data points whose error is less then ±10%. Moreover, the error of all data points is less than ±20% (Table 2).

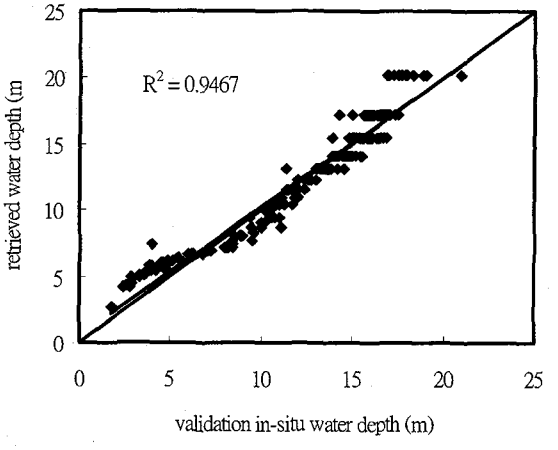

Figure 2. The comparison of retrieved water depth and validation in-situ data with non-classification.

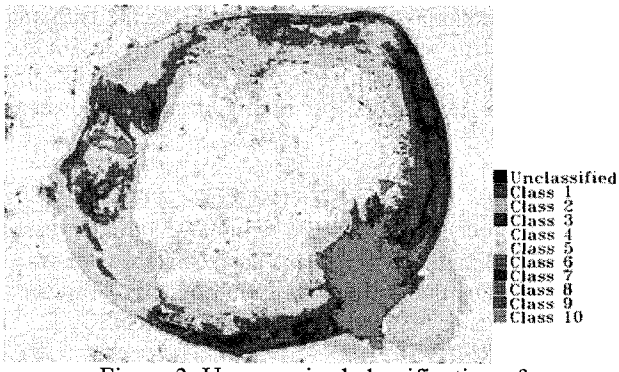

Figure 3. Unsupervised classification of substrate in Dong-Sha Atoll from SPOT image.

Table 1. The accuracy of regression data

Accuracy \ Data / Error	unclassified	Class 4	Class 5	Class 6
	445	301	98	33
±5%	71.5%	88.7 %	66.3 %	36.4 %
±10%	87.6%	100 %	78.6 %	51.5 %
±20%	90.6%	100 %	84.7 %	84.8 %

Table 2. The accuracy of validation data

Accuracy \ Data / Error	unclassified	Class 4	Class 5	Class 6
	423	308	81	22
±5%	70.2%	84.4 %	61.7 %	59.1 %
±10%	84.6%	97.7 %	69.1 %	68.2 %
±20%	90.7%	100 %	76.5 %	86.4 %

In class 5, the regression function is

$$Y = -5.4142X + 23.224 \quad (6)$$

The R^2=0.85 for the regression data set. Figure 3b describes the R^2 as 0.92 for the validation data set. The retrieved water depth is large than in-situ water depth around 5m. Table 1 indicates that the error of 66.3% data points is less than ±5% in regression data set. Besides, when the errors are ±10% and ±20%, the data points will be 78.6% and 84.7% respectively. As for the validation data set, there are 61.7%, 69.1% and 76.5% data points whose errors are ±5%, ±10% and ±20%.

When the regression data set of class 6 is put into Eq.(3), the regression function can be found as

$$Y = -4.6623X + 18.99 \quad (7)$$

The R^2=0.96 for the regression data set. Besides, the R^2=0.95 for the validation data set. Figure 3c shows the retrieved water depth is less than in-situ water depth while the in-situ water depth is shallower than 5m. Table 1 shows there are 36.4%, 51.5% and 84.8% regression data points whose errors are ±5%, ±10% and ±20% respectively. As for validation data set, when the error are ±5%, ±10%, and ±20%, the data points will reach 59.1%, 68.2% and 84.6% respectively (Table 2).

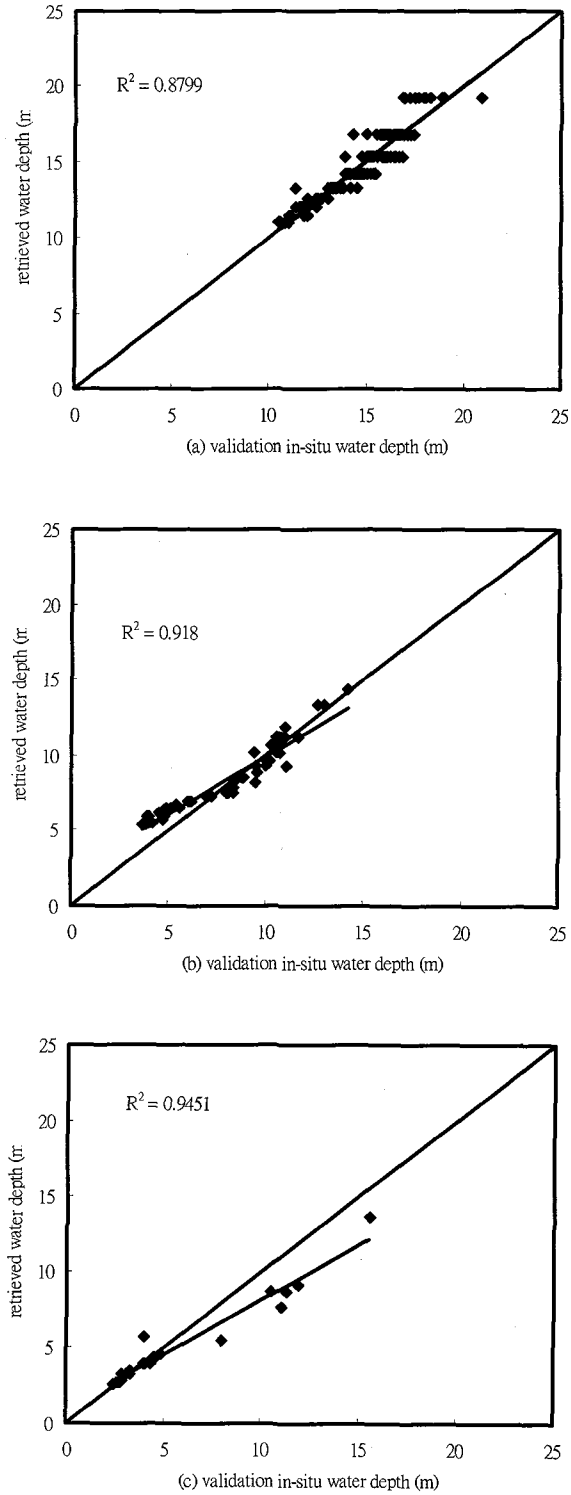

Figure 3. The comparison of retrieved water depth and validation in-situ data (a)at class 4 (b) at class 5 (c) at class 6

Table 3 shows the standard error of retrieved water depth, the standard error are 0.86m and 0.92m for the regression and validation data sets of non-classification. Under the classification process, the standard errors are

0.49m and 0.63m for the regression data set and validation data set in Class 4. In Class 5, the standard errors of regression and validation data set are 0.93m and 0.61m. In Class 6, the standard errors are 0.46m and 0.68m for the regression data set and validation data set respectively.

According to the above results, the coefficient of determination in classification is less than the result of non-classification, but the standard error of classification is less than the result of non-classification. Figure 4 shows the bathymetry mapping retrieved from classification process. The white area indicates the cloud, land and shoal cover area. Most of the water depths are between 10 and 20m inside the Dong-Sha Atoll. Besides, most of the water depths are shallower than 5m above the Dong-Sha Atoll. It is full of hazard for navigation to the north of Dong-Sha Island because of shallow water. Otherwise, it is safer for navigation to the south of Dong-Sha.

Table 3. The standard error of retrieved water depth

stand \ class / error	Regression data (m)	Validation data (m)
unclassified	0.86	0.92
Class 4	0.49	0.63
Class 5	0.93	0.61
Class 6	0.46	0.68

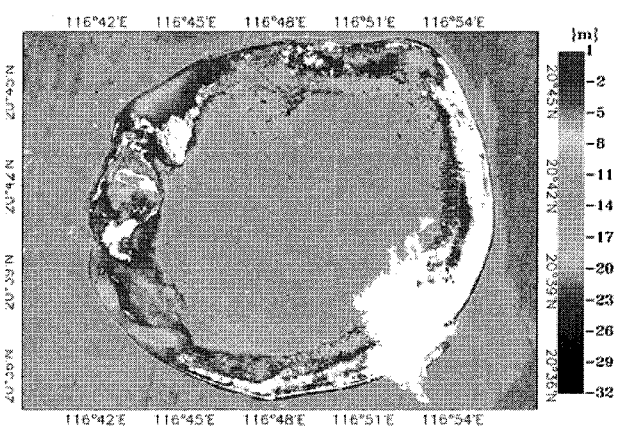

Figure 4. The bathymetry map

5 CONCLUSION

In this study, the coefficient of determination R^2 is 0.95 and there are above 85% data points whose error is below ±10% for the non-classification condition. In this condition, the standard error is less than 0.92m. The result presents the good accuracy of the retrieved water depth.

Through the classification, the coefficient of determination of all Classes is more than 0.85. When the error is ±10%, the data points are more than 68% except the 51.5% of Class 6. Especially, the data points can be more than 97% for Class 4. Besides, the standard error is less than 0.68m for all Classes except Class 5. Therefore, it is more accurate in classification condition than the result of non-classification. According to the bathymetry map, most of water depths are shallower than 5m above the Dong-Sha Atoll. Most of water depths inside Dong-Sha Atoll are deeper than 10m and shallower than 20m.

6 ACKNOWLEDGMENTS

We appreciate the CSRSR National Central University for providing the SPOT image data. This research was supported by the National Science Council of Taiwan through grants NSC94-2611-M019-14 and NSC 95-2611-M-019 -011.

7 REFERENCES

Blyth, K, 1981. Remote Sensing in Hydrology. Report No. 74, Institute of Hydrology, Wallingford, pp. 170.

Doak, E, J. Livisay, D. Lyzenga, J. Ott, and F.C. Polcyn, 1979. Landsat offshore studies along the western coast of Libya, ERIM report No. 30700-1-F.

Gross, M. Grant, 1992. *Oceanography*, 6th ed., Prentice-Hall, pp446.

Irish, J. L. and W. J. Lillycrop, 1999. Scanning laser mapping of the coastal zone: the SHOALS system, *ISPRS Journal of Photogrammetry & Remote Sensing*, 54, pp.123–129.

Islam, A., J. Gao, W. Ahmad, D. Neil, and P. Bell, 2004. A composite DOP approach to excluding bottom reflectance in mapping water parameters of shallow coastal zones from TM imagery, *Remote Sensing of Environment*, 92, pp. 40-51.

Jerlov, N. G, 1951. Optical Studies of Ocean Waters, Reports of the Swedish Deep sea Expedition, 3(1) pp .3-57.

Lafon, V., J.M. Froidefond, F. Lahet, and P. Castaing, 2002. SPOT shallow water bathymetry of a moderately turbid inlet based on field measurements, *Remote Sensing of Environment*, 81, pp. 136-148.

Leu, L. G., Y. Y. Kou, and C.T. Liu, 1999. Costal Bathymetry from the Wave Spectrum of SPOT Images, *Coastal Engineering Journal*, 41(1), pp. 21-41.

Liu, C. T., Y. J. Chyou, D. W. Wang, and C. W. Lee, 2005. Verification of Satellite Observed Ecosystem of Corals, In: *The 16th APEC Workshop on Ocean Models and Information System for the APEC Region*, Ho Chi Minh City, pp. 1-1,1-6.

Tripathi, N. K. and A. M. Rao, 2002. Bathymetric mapping in Kakinada Bay, India, using IRS-1D LISS-III data, *Int. J. Remote Sensing*, .23(6), pp. 1013-1025.