Mapping the coastal bathymetry with FORMOSAT-2 image

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Abstract- **In this study, the FORMOSAT-2 satellite data was used to estimate the bathymetry directly or through unsupervised classification first. Both the satellite retrieved water depths were corrected by the in-situ tidal data. The no-classified results show that more than 82% satellite-derived water depths have the error below 20% comparing with the in-situ data. Meanwhile, its root mean square error is 2.5 m. After classification, it is found that class 4 and 5 are located on the water region. Therefore, the retrieved water depth can be calculated just in class 4 and 5 regions. At class 4, there are 77% of data points having the error less than 20%. Its root mean square error is 2.7m. At class 5, more than 81% data points with the error below 20% and its root mean square error is 1.0m. The results indicate that the shallow water depth could be mapped accurately from FORMOSAT-2 image. Moreover, the satellite data has the potential to become an important tool for bathymetry map based on its spatial coverage, frequent interval, and safety.**

I. INTRODUCTION

Almost only the visible light can penetrate the sea water deeper while the solar radiance arrives the water surface (Blyth, 1981). The visible light penetrates the water, can be reflected by sea bottom, and arrives the satellite sensor. The visible light may attenuate due to scattered and absorbed by water mass and suspending material. The feature of attenuation can be used to calculate water depth that is the main concept of bathymetry retrieved from remote sensing data. In the clear water, the transmittance of blue ray (0.45~0.52μm), the most penetrable, is around 60% and the transmittance will rapidly reduced when the wavelength increases (Jerlov, 1951). The sensor of Landsat 4 includes blue band (0.4μm ~0.52μm) and green band (0.5μm ~0.6μm), it has better capacity for penetrating waters, and thus is more suitable for analysis and research of shallow water depths (Tanis and Hallada, 1984; Tanis and Byrne, 1985; Lyzenga, 1985).

Lin (2001) calculated the capacity and accuracy of surveying and mapping shallow water depths using IKONOS high-resolution satellite image. The accuracy of the estimated water depth within 10 m can reach 30 cm. Lyu (2004) used the QuickBird satellite image with higher resolution to study the shallow water depth in Kenting South Bay. The error value of surveying and mapping depths from 0~30m is within 30%.

The precise determination of the shallow water depth and short-term bathymetric maps are essential to near shoals and banks, navigation and ocean engineering. The incident light reflectance from water bottom will provide water depth information. Moreover, the transmittance of blue light is greater than the other visible lights. Therefore, the consideration through light reflection (especially, blue light) maybe is a good choice to water-depth computation. In this study, the multi-channel satellite data from FORMOSAT-2 is used to retrieve water depth in the coastal area. The satellite imagery provides at low cost, complete, and repetitive maps of areas that are difficult to map by traditional field measurement.

II. DATA and METHODOLOGY

The FORMOSAT-2 is a sun-synchronous satellite. One of the payloads is the multi-spectral sensor, it includes blue (0.45-0.52μm), green (0.52-0.60μm), red (0.63-0.69μm), and near infrared (0.76-0.90μm) bands (Table 1). Meanwhile, its spatial resolution is 8 m and image swatch is 24 km. A FORMOSAT-2 image data, acquired on April 22, 2006 (Figure 1), will be used to estimate the depth of the coastal shallow water around Yilan, located in the northeast coast of Taiwan. Besides, the tidal data near Yilan is also considered to remove the tide effect. Finally, the in-situ water depth data, measured by echo sounder from May to July in 2006, will be used to evaluate the retrieved water depth.

Since the blue light can penetrate water more deeply, the blue band data from FORMOSAT-2 can be used to retrieve the coastal water depth in Yilan by the algorithm expressed as:

$$P_{SN} = P_{AN} + P_{DN}\exp(-GKZ) \ , \qquad (1)$$

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

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Where Z is the water depth, P_{SN} is the satellite signal level, P_{AN} is the signal level from deep water including atmospheric path, P_{DN} is the reference signal of bottom, K is the attenuation coefficient, and G is the geometric factor (~2). Besides the satellite signal in this study was also classified first by unsupervised method with the spectral characteristics of FORMOSAT-2 full band data. Both the satellite retrieved water depths were corrected by the same in-situ tidal data.

III. RESULTS and DISCUSSION

In this study, FORMOSAT-2 multi-spectral visible data is used to estimate water depths in the coastal shallow water area of Yilan. Since the near infrared is almost absorbed by water, the near infrared data of FORMOSAT 2 can be used to identify the location of territorial and cloud. For cloud-free pixel, the water depth can be estimated from FORMOSAT 2 blue band data directly called unclassified water depth. Moreover, the bathymetry is also estimated with full band classification first, called classified water depth. The major results through two different schedules are shows as follows:

(1) unclassified water depth

The in-situ tide corrected data were randomly separated into two sets. There were 105 data for regression and 106 data for validation. Figure 2 is the comparison of retrieved water depth and in-situ data. The coefficients of determination (R^2) are 0.79 for the regression data set and 0.75 for validation data set. Table 2 shows that 57.1% and 86.7% of data points of the regression data set have ±10% and ±20% errors from in-situ water depth for cases of no-classification. Besides, when the error is ±30%, the percentage reaches 92.4%. In the case of validation data set, there are 54.7% and 82.1% data points whose errors are less than ±10 and ±20%, respectively. Meanwhile, Table 2 also indicates the data point percentage reaches 90.6% with error less ±30%.

(2) classified water depth

To increase the accuracy of retrieved water depth, the FORMOSAT-2 image is classified into 20 classes (Figure 2). It is found that class 1 has no data and that class 4, 5, and 6 represent water cover area, respectively. Classes 5 and 6 are combined together because there are few in-situ data points in the class 6. Therefore, only classes 4 and 5 are discussed below.

After classification, the tidal corrected in-situ data are randomly divided into two sets. One is for regression, and the other is for validation (Table 2). For the class 4, the coefficient of determination (R^2) of the regression data set is 0.76 (Figure 4a). R^2=0.69 is for the validation data set. Table 2 shows that 60.3% data points of regression data set have ±10% error of in-situ water depth. There are 86.8% and 97.1% of all data points have the error less than ±20% and 30% from the in-situ water depth. As shown in Table 2, the error of 52.2% validation data points is less than ±10%. The errors less than ±20% and ±30% correspond to 76.8% and 92.8% of data points, respective, in the class 4.

For class 5, applying the regression data set and satellites data, its R^2 is 0.19 for the regression data set (Figure 4b). From Table 2 one can see that 62.2% data points of the regression data set have ±10% error. The errors are less than ±20% and ±30% corresponding to 81.1% and 86.5% of data points, respectively. The result of validation data set shows that 64.9% data points have ±10% error. There are 81.1% data points with error less then ±20% and 89.2% data points with error less than ±30%.

From Table 3, one can see that the root mean square errors of retrieved water depth are 2.5m and 2.2m for the regression and validation data if the data sets has no classification first. With classification process, the root mean square errors are 2.3m and 2.7m for the regression data set and validation data set for the class 4 and 1.0m and 0.8m for class 5, respectively.

The above results show the coefficient of determination as well as the root mean square error in classified data is less than that of unclassified. Figure 5 presents the bathymetry mapping retrieved from classification process. The black area marks the land, shoal, and deep sea region.

IV. CONCLUSIONS

Regression analysis between the measured water depth and FORMOSAT-2 imagery data is carried out. For unclassified data, the coefficient of determination, R^2, is found to be 0.75, and there are over 82% of data points whose error is below ±20%. The root mean square error is less than 2.5m. The result represents high accuracy for the retrieved water depth.

With the classification process, the coefficient of determination of all classes is more than 0.69. Furthermore, the error is ±20%, the data points are more than 77%. Besides, the root mean square error is less than 2.7m for class 4 and 1.0m for class 5. Therefore, it can be concluded that the estimated water depth through the classification method can get higher accuracy. In addition, the coefficient of determination of the class 5 is not high due to less in-situ data points. These results show that FORMOSAT-2 image is well suited for mapping the bathymetry of shallow and clear water, especially for the complicated maritime autonomy area.

ACKNOWLEDGMENT

This study is supported by the National Science Council under Grant No. (NSC 98-3114-E-019-002 and NSC 98-2611-M-019-016-MY3). In addition, the author would like to thank the National Space Organization and Center for Space and Remote Sensing, and the National Central University for providing FORMOSAT-2 satellite data.

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Table 1. Characteristics of FORMOSAT-2

Parameter	Description
Orbit	sunsynchronous
Panchromatic(PAN)	0.45~0.90µm
Multispectra (MS)	0.45~0.52 µm 0.52~0.60µm 0.63~0.69µm 0.76~0.90µm
Spatial resolution	PAN 2 m MS 8 m
Swath	24 Km
Altitude	891 Km
Orbit repeat (day)	1

Table 2. The accuracy of retrieved water depth

		Surveying Point	±10 %	±20 %	±30 %
Unclassified	Reg. Group	105	57.1%	86.7 %	92.4 %
	Val. Group	106	54.7%	82.1%	90.6 %
Class 4	Reg.Group	68	60.3%	86.8 %	97.1 %
	Val. Group	69	52.2%	76.8 %	92.8 %
Class5	Reg. Group	37	62.2%	81.1 %	86.5 %
	Val. Group	37	64.9%	81.1%	89.2 %

Table 3.The root mean square error of retrieved water depth

	Regression data (m)	Validation data (m)
Unclassified	2.5	2.2
Class 4	2.3	2.7
Class 5	1.0	0.8

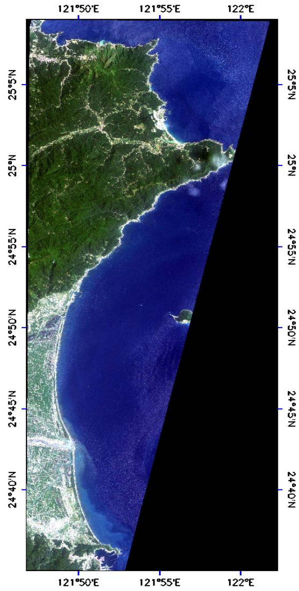

Figure 1. True color image of FORMOSAT-2, acquired at 1:59:02 on April 22, 2006.

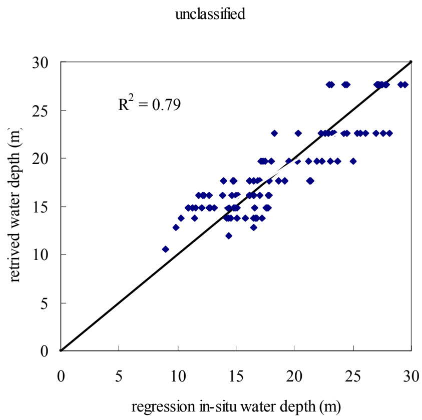

Figure 2. The comparison of retrieved water depth and in-situ data with no-classification.

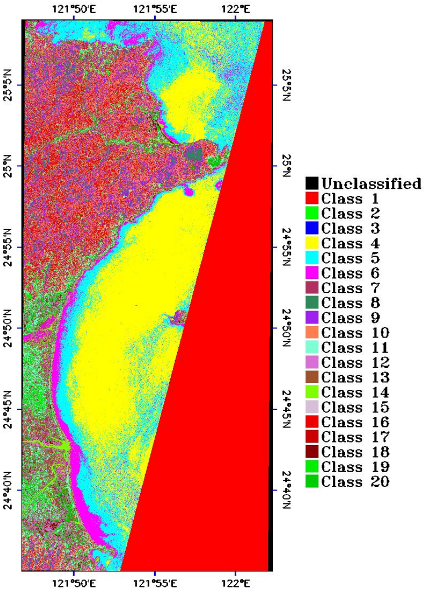

Figure 3. The map of classification from the spectral characteristics of FORMOSAT-2.

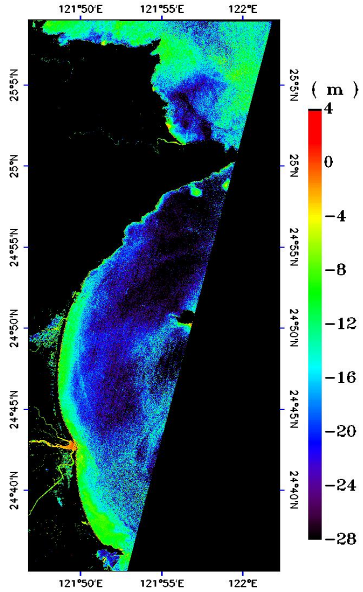

Figure 5. The bathymetry map retrieved from classified model

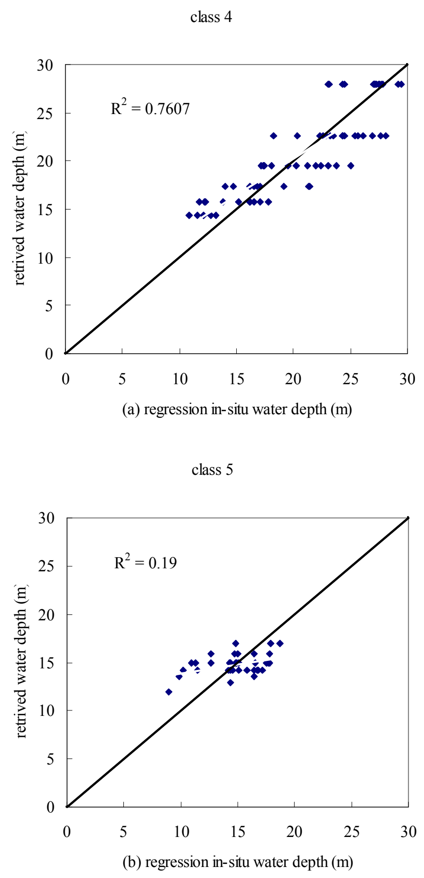

Figure 4. The comparison of retrieved water depth and in-situ data at (a) class 4, (b) class 5.