Conference Paper

Satellite Derived Bathymetry on Shallow Reef Platform: A Preliminary Result from Semak Daun, Seribu Islands, Java Sea, Indonesia

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Abstract

Derivation of the bathymetric model from satellite imaging for non-navigable coastal waters has been developed. It is the purpose of this presented paper to assess the depth accuracy of the bathymetric model derived from such optical satellite imagery. The study domain is situated in the Semak Daun reef platform, Java Sea, Indonesia. The area represents shallow sub- and inter-tidal water with various benthic covers. Satellite imagery used here is retrieved from the European Space Agency Sentinel-2 satellite observation system. Two methods in deriving bathymetry from optical imagery are used. The first one is the empirical band ratio transform algorithm and the second one is the analytical approach. Coefficients involved in both models are obtained from means of calibration against sounding data from a single-beam echo-sounding survey. About 9% of sounding data are used for the calibration, while the rests are used to validate the resulting bathymetric models. It is found that both methods can successfully be applied at depth of up to 10 m. The root mean square errors indicated by both models are comparable. Accuracy measures in the order of 1.9 m are obtained with a coefficient of determination of 0.7. The results presented here confirm the applicability of satellite-derived bathymetry for mapping shallow seabed complying to the category zone of confidence C as of the International Hydrographic Organization standard. It should be bear in mind that such an assessment is typical for the environmental condition considered in this study.

Keywords: single-beam echo-sounding, transform algorithm, analytical approach

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1. Introduction

Over the past years, the acquisition technologies of bathymetry surveying have been developed from the shipborne to the airborne platform and recently using the space-borne acquisition [1]. Satellite-derived bathymetry (SDB) is one of the developing applications of space-borne acquisition which using the optical remote sensing observation. SDB data offers depths with low-cost and rapid works compared to other known bathymetry retrieval techniques, like *in-situ* survey [2].

According to the United Kingdom Hydrography Office (UKHO), the good quality of SDB data is considered to give valid information. It can be used to make navigational products safer. In October 2015, the UKHO published the first nautical chart that derived from the combination of various surveying technologies. It is explained that SDB data has the potential to be a solution to updating charts in areas that are arduousto reach by shipborne and airborne technologies [3].

The previous study shows that several methods can be used to derive the bathymetry data from satellite images. This research adopts the two basic methods of determining bathymetry from optical imagery. The first one is the empirical band ratio transform algorithm by Stumpf and the second one is the analytical approach by Lyzenga. Both methods assume that there is a mathematical relationship between the remotely sensed radiance and water depth. Coefficients that involves in both methods are obtained utilizing calibration against sounding data from the single-beam echo-sounding survey.

This paper aims at assessing the applicability of both methods for deriving bathymetry from a multispectral satellite image. It is also the intention of this research to assess the quality of SDB by estimating the corresponding accuracy 95% and its position in Category of Zone of Confidence (CATZOC). CATZOC constitutes as the indicator of accuracy data presented on charts. CATZOC is divided into six categories (A1, A2, B, C, D, U) as A1 constitutes the best one. This standard is needed for the safety of marine transportation. Furthermore, this study is expected to generate an alternative bathymetric map for the shallow areas in the study area.

2. Data and Method

2.1. Measuring bathymetry using remote sensing

On the satellite derived bathymetry, the total upwelling radiance (Lt) recorded by the remote sensor consists of four components such as atmospheric path radiance (Lp), specular radiance (Ls), subsurface volumetric radiance (Lv), and the bottom radiance (Lb) [4].

$$L_t = L_p + L_s + L_v + L_b \tag{1}$$

The atmospheric path radiance (Lp) is the radiance recorded by a sensor resulting that never reaches the water surface. Specular radiance (Ls) is the radiance that reaches the water surface. The subsurface volumetric radiance (Lv) is the radiance that penetrates the water column but never reaches the seabed. The bottom radiance (Lb) is the radiance that reflected from the seabed.

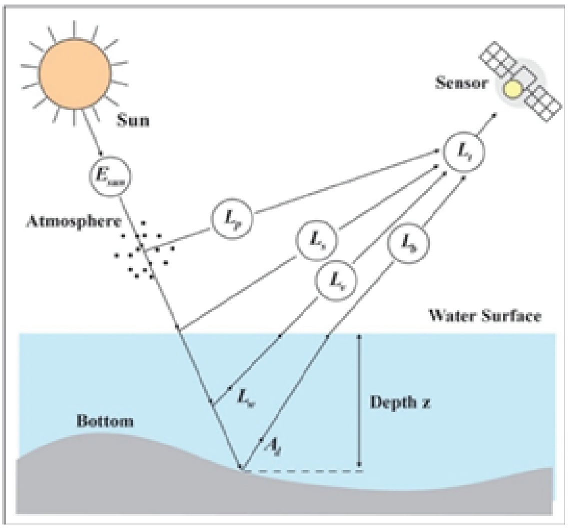


Figure 1: Four components of the total radiance measured by a remote sensor.

To retrieve the depth information, the bottom radiance must be separated from the total upwelling radiance. This can be realized by using the atmospheric correction [5] to efface the atmospheric radiance (L_p), sun-glint correction [6] to efface the specular radiance (L_s), and deep-water correction to efface the subsurface volumetric radiance (L_v). The deep-water radiance (L_∞) consists of three components such as the atmospheric radiance, specular radiance, and subsurface volumetric radiance since the bottom radiance remains zero as it is a very deep area. Assuming that the subsurface volumetric radiance in shallow water is the same as deep water, the deep-water radiance (L_∞) can be used to correct the subsurface volumetric radiance in shallow water [7].

With the Beer's law as the basis, Lyzenga (1978) and Philpot (1989) proposed a linear model for retrieving depth information:

$$L = L_\infty[1 - \exp(-gz)] + A_d \exp(-gz) \tag{2}$$

where L = the remote sensing radiance, L_∞= the deep-water radiance, g= two-way attenuation coefficient, z= water depth, and A_d= the upwelling radiance from the bottom. Based on equation (2), the depth can be retrieved by using a single band as shown in equation (3).

$$z = g^{-1}[\ln(A_d - L_\infty) - \ln(L - -L_\infty)] \tag{3}$$

Afterward, Lyzenga (1985) develop a bathymetry analytical method that using two or more spectral bands by assuming that the water quality consistent within an image so that the ratio of attenuation coefficients for a pair of bands is constant over an image as shown in equation (4).

$$z_{est} = \alpha_0 + \sum_{i=1}^{N} \alpha_i \ln[L(\lambda i) - L_\infty(\lambda i)] \tag{4}$$

Where z_{est}= depth obtained by satellite, N= number of the spectral bands, α_0= coefficient derived from calibration, α_i= coefficients derived from calibration, and $L(\lambda_i)$= the remote sensing radiance for band λ_i,L_∞= the deep water radiance for band λ_i.

Besides the analytical method by Lyzenga (1985), Stumpf et al (2003) proposed a log-ratio bathymetry method to retrieve the depth. Stumpf developed this non-linear bathymetric inversion model using two bands as follows:

$$z_{est} = m_1 \frac{\ln(R(\lambda_b))}{\ln(R(\lambda_g))} + m_0 \tag{5}$$

Where z_{est}= depth obtained by satellite, m_0 and m_1= coefficients derived from calibration, $R(\lambda_b)$ and $R(\lambda_g)$= remote sensing radiance for bands (blue and green). This method used green and blue bands due to the characteristic of these bands which can penetrate up to 20 m. As the depth increases, the band with a higher absorption rate will decrease proportionally faster than the band with a lower absorption rate. Thus, the ratio between both bands will increase as depth increases.

To minimize depth estimation error for both methods, wavelength bands with the smallest attenuation is used. The basic band used for SBD is the blue light spectrum (440 to 540 nm) as it has the smallest attenuation and can penetrate water up to 30 m in optimal conditions. The green light (500 -- 600 nm) has a longer wavelength and it can penetrate approximately 15 m, and the red light (600 -- 700 nm) can penetrate to 5 m.

3. Data

3.1. Sentinel-2 Observation

Sentinel-2 satellite is a part of the European Space Agency (ESA) with high-resolution multi-spectral imagery. Sentinel-2 imagery data is used to analyze and estimate the depth. Data used in this research is acquired through Copernicus mirror site. The imagery is taken at the date of 5th January 2018 at 10 am. The obtained data are Level 2A of Sentinel-2 which the products have been processed on cloud screening and atmospheric corrections. Other than that, this product already radiometric and geometric has been corrected. In this study, there are three multispectral bands that are used: blue, green, and red band. The spatial resolution of this image is 10 m.

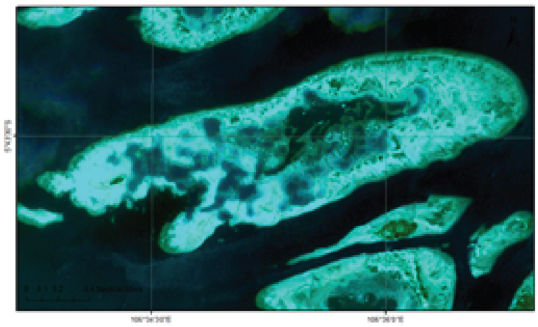


Figure 2: Sentinel-2 Optical Imagery (Green and Blue bands) on January 5th, 2018.

3.2. Sounding Data

The sounding data is carried out in 2004 by single-beam echo-sounder. The domain area of the sounding line is located in all over the Karang Lebar. Overall accuracy of this sounding data is ±0.61 m [8]. Some parts (about 9%) of sounding data is used to calibrate the models and the rests are used to validate the resulting bathymetry. This part of sounding data consists of 543 depth sounding data as shown in Figure 2.5. This sounding data are used for calibration to derive the coefficients.

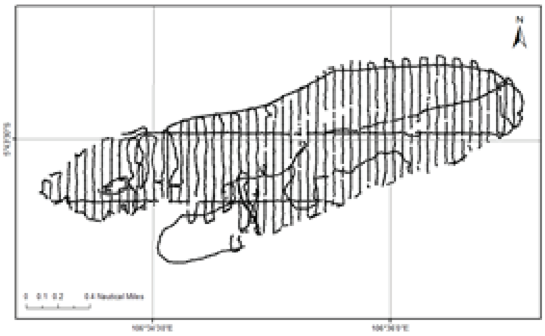


Figure 3: Sounding data.

3.3. Coefficients' Determination

To estimate bathymetry derived from satellite, all bathymetric inversion methods must be calibrated with sounding data. The calibration data is in the red box area as it is shown in Figure 3. This calibration area is picked based on manual (visual) interpretation of the imagery which represents various types of reef zones and benthic cover in Karang Lebar. This area is picked subjectively and very dependent on the perception of each person.

The selection of the calibration area is done repeatedly before, in several different places. This area finally selected as the calibration area because it has the smallest RMSE value than another area. In this area, there are 543 out of 6896 sounding data that are used for the calibration (about 9% data are used to calibrate).

The analytical method for three spectral bands has four coefficients (α0, α1, α2, α3) and the log-ratio method for two bands has two coefficients (m0, m1). The coefficients for both the analytical method and the log-ratio method are obtained from linear regression. The differences between both methods are the determination of the coefficients. For the analytical method, coefficients are determined using the multiple linear regression, meanwhile, the coefficients for the log-ratio method are determined using the simple linear regression. For both methods, the coefficients can be obtained from the matrix equation (6).

$$X = \left(A^T A\right)^{-1}(A^T z_{SBES}) \tag{6}$$

Where X= the coefficients derived from callibration, A= the remote sensing radiance, and z_{SBES}= depth obtained from single-beam echo-sounder.

3.4. Validation

By knowing the coefficients, depth obtained from SDB can be known. The validation is conducted to know the quality of depth obtained from SDB by using the rest of the sounding data. The accuracy of the model is assessed from the residual between depth obtained from SDB and depth obtained from single-beam echo-sounder. Depth obtained from SDB needs to be assigned at CATZOC level which can be seen in Table 1.

Table 1: CATZOC Levels.

CATZOC Level	Depth Range (m)	Accuracy (±m)
A1	0 - 10	0.6
	10 - 30	0.8
A2 & B	0 - 10	1.2
	10 - 30	1.6
C	0 - 10	2.5
	10 - 30	3.5

4. Result

4.1. Accuracy Assessment

Depth obtained from SDB are plotted with depth obtained from single-beam to know the correlation among them. Scatter plots in Figure 4 show a strong correlation between depth obtained by SBES and depth obtained by SDB. This strong correlation can be particularly observed for shallow depths below 10 m.

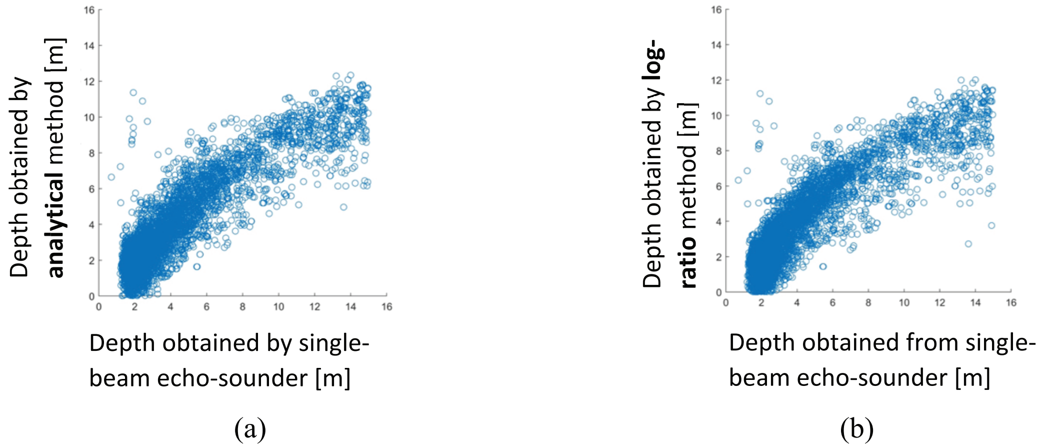


Figure 4: Scatter plot of results depths obtained by single-beam echo-sounder vs (a) analytical method (b) log-ratio method.

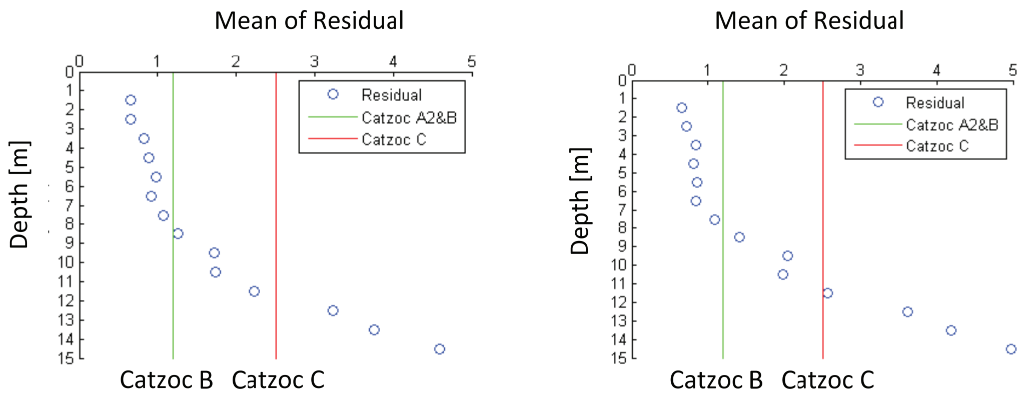
The root mean square error (RMSE) also calculated in each depth range as it is shown in Table 2. From these results, errors for both methods are higher in the deep depth. The lowest residual found at depth of 1-2 m for both methods. Up to 15 m depths, the RMSE reaches 4 m. Both the analytical method and the log-ratio method perform very similarly in overall accuracy.

In accordance with Table 2, the scatter plot between depth and mean of residual are made. It shows the correlation between depth and mean residual to characterize the CATZOC level. Based on the figure below, all SDB estimates comply with the CATZOC C level.

Figure 6 shows the DEM of difference (DoD) between single-beam echo-sounder and SDB. The depth differences between SDB and single-beam echo-sounder varies from -2.0 m to 4.0 m. The shallower bathymetry, the smaller the depth differences. Conversely, the deeper bathymetry, the wider it is. There are at least three main reasons for this situation. The first one is the limitation in-depth penetration. As it is stated before that the blue light can penetrate water up to 30 m in optimal conditions, the green light can penetrate approximately 15 m, and the red light can penetrate 5 m. The second

TABLE 2: Residual and Standard Deviation in Each Depth.

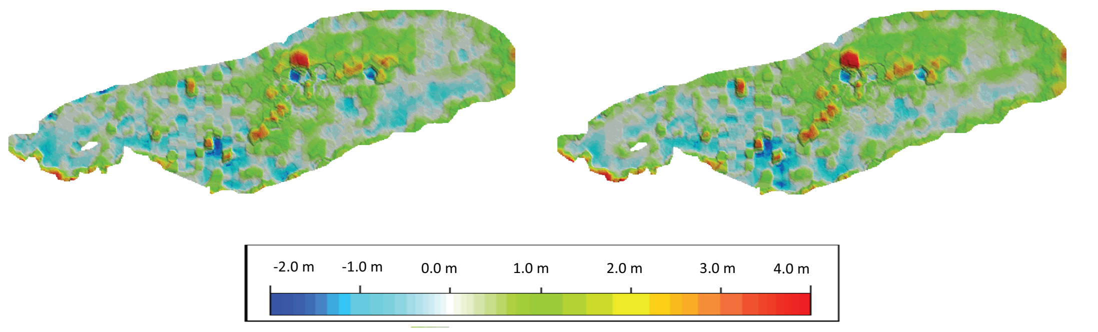
Range of Depth (m)	Amount of Data	Analytical Method		Log-ratio Method	
		Mean of Residual (m)	Standard Deviation	Mean of Residual (m)	Standard Deviation
1 - 2	1494	0.65	0.70	0.66	0.9
2 - 3	2418	0.65	0.58	0.72	0.89
3 - 4	781	0.83	0.68	0.84	1.07
4 - 5	586	0.89	0.74	0.81	1.02
5 - 6	397	0.98	0.77	0.85	1.14
6 - 7	270	0.93	0.82	0.84	1.16
7 - 8	176	1.07	0.97	1.09	1.27
8 - 9	119	1.27	1.08	1.41	1.33
9 - 10	109	1.72	1.28	2.05	1.41
10 - 11	120	1.73	1.25	1.98	1.33
11 - 12	94	2.23	0.95	2.57	0.98
12 - 13	95	3.23	1.22	3.61	1.30
13 - 14	121	3.75	1.37	4.18	1.56
14 - 15	97	4.56	1.42	4.98	1.61



(a) (b)

Figure 5: Plot of residual (a) analytical method (b) log-ratio method.

one is the effect of the water turbidity on the Semak Daun reef platform. This water turbidity causes higher attenuation that makes light intensity decrease. The third one is the variations in the bottom albedo. It is caused by the different acquisition times of the data. The sounding measurement is obtained in 2004 and the Sentinel-2 data is obtained in 2015.

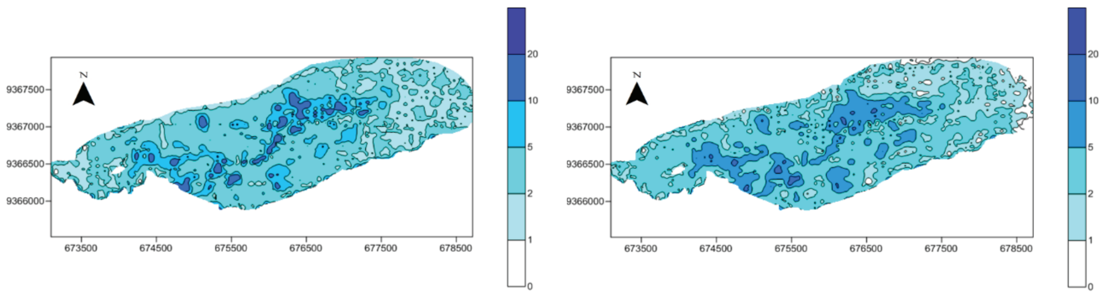


(a) (b)

Figure 6: DEM for (a) single-beam echo-sounder and analytical method, (b) single-beam echo-sounder and log-ratio method.

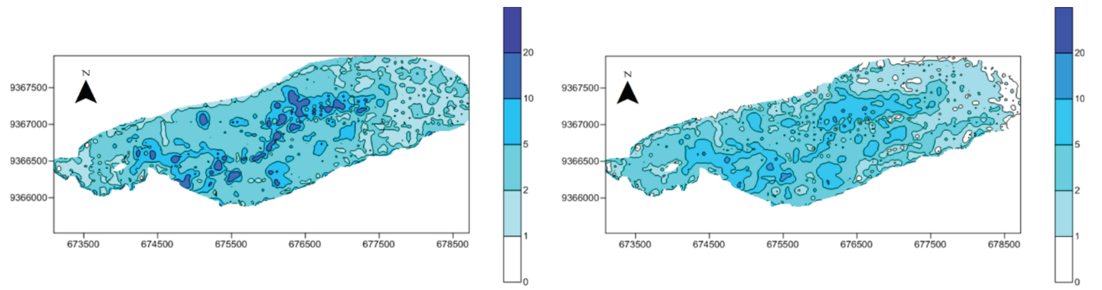
4.2. Bathymetric Map

The alternative bathymetric maps are generated in this research in order to perform the visual of the bathymetry depth. Figure 7, Figure 8, and Figure 9 show the bathymetry depth obtained by single-beam echo-sounder data, depth obtained by analytical method, and depth obtained by the log-ratio method. The data are presented as color-coded depths ranging from 0 to 14 m.



(a) (b)

Figure 7: Bathymetry derived from (a) single-beam echo-sounder (b) analytical method.



(a) (b)

Figure 8: Bathymetry derived from (a) single-beam echo-sounder (b) log-ratio.

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5. Conclusions

Based on the obtained results, this research concludes that:

1. Analytical and log-ratio methods can successfully be applied to obtain bathymetry from Sentinel-2 satellite imagery.
2. Both methods produce up to 10 m depths within 2 m accuracy. These results comply with CATZOC C.
3. Alternative bathymetric maps for the shallow areas can be made.

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