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Bathymetry Mapping Using Landsat 8 Satellite Imagery

Jagalingam P[1], Akshaya B J[1] and Arkal Vittal Hegde[2]

[1,2]Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal - 575025, INDIA.

Abstract

Bathymetry is the science of determining the topography of the seafloor. Bathymetry data is used to generate navigational charts, seafloor profile, biological oceanography, beach erosion, sea level rise, etc. A number of methods are available for determining ocean bathymetry, using either active sensor such as sonar, lidar or passive multispectral imagery such as Ikonos, WorldView and Landsat. Determining the bathymetry using sonar and LiDAR is very expensive, while Ikonos and Worldview are commercially available multispectral satellite platforms whereas Landsat satellite imagery provides a free and publicly available data. Therefore, the present study makes an attempt to determine the bathymetry mapping of the southwest coast of India (13° 0' 0" N and 74°50' 0" E) by applying the ratio transform algorithm on the blue and green bands of Landsat 8 satellite imagery. The statistical indices such as R^2, RMSE and MAE are computed between the algorithm derived value and the hydrographic chart sounding value. The result shows a good correlation between the algorithm derived value and hydrographic chart sounding value.

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Keywords : Bathymetric; Landsat-8; Ratio transform algorithm; Hydrographic chart

1. Introduction

The ocean covers 70% of the earth's surface, wherein it has several unique parameters such as wind, tide, wave, Bathymetry, sediment, marine life etc., required to understand the behavior of the coastal environment. The wide spread ocean has both advantages and disadvantages. The ocean plays a significant role in the development of the country's economy, and also offers navigation through the ocean, which helps to connect the different countries for trade. Bathymetry information is one of the important parameters which plays a major role in planning near-shore structure activities such as engineering work, port management, pipeline laying, fishing, dredging operation,

* Corresponding author. Tel.: 8867824564
E-mail address: am13f05@nitk.edu.in

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oil drilling, aquaculture, etc., and it is also significantly important to determine the underwater topography, movement of sediments and to generate the hydrographic chart for safety transportation. Bathymetry data are very much essential throughout the year to predict the sediment level to maintain the man-made channel depth for smooth navigation. Historically, bathymetry was determined by using conventional methods such as pre-measured rope or cable passage, placed on the side of the vessel ship and allowed to reach the seabed. This method can retrieve the depth of a single point in time. This method is time consuming and inefficient.

In order to overcome this inefficiency, method was rapidly replaced by the acoustic echo-sounding technique. The technique has two approaches, namely single-beam echo sounder (SBES) and multi-beam echo sounder (MBES). Transducers are placed over the side of the vessel, which transmit the sound waves to the sea bottom and receive the reflected waves. The amount of time taken for the sound waves to reach sea bottom and reach back to the receiver is used to determine the depth. Typically, SBES transmits and receives sound waves of single point, wherein the MBES transmits sound waves in all directions and receives sound waves from multiple points, and thus it has an advantage to map the depth over the widest range. Echo-sounding method is capable of determining the depth accurately over the clear water, coastal environment where as in turbid water, the method lacks performance due to infiltration of sound waves to the bottom of the ocean.

Recently, various airborne laser bathymetric (ALB) light detection and ranging (LiDAR) systems, such as Scanning Hydrographic Operational Airborne Lidar Survey (SHOLAS), Compact Hydrographic Airborne Rapid Total Survey (CHARTS), Laser Airborne Depth Sounder (LADS), and Experimental Advanced Airborne Research Lidar (EAARL) are adopted to determine the bathymetry of the ocean. This method can effectively determine the depth of both shallow and clear water, but this technique is only limited by its high purchasing and maintenance costs. Almost all the above techniques are expensive.

Remote sensing can be regarded as one of the most promising alternative tool to map the bathymetry of the ocean, because of its extensive coverage of the area, low cost and repeativity. In recent years, successful launches of remote sensing satellites such as Ikonos, QuickBird, and Worldview-2 offer imageries with both high spatial and spectral resolution, but all these images need to be procured commercially. Since the procurement of commercially available images proves to be expensive for most of the developing countries. In the present work, application of the freely available landsat 8 imagery data is done to map the bathymetry of the ocean. Landsat-8 imageries are downloaded from the U.S. Geological Survey (USGS) website and used to determine the bathymetry of the ocean.

A number of empirical algorithms are available in the literature such as Su et al. (2008); Stumpf et al. (2003); Su et al. (2008) and analytical algorithms such as Lyzenga (1978, 1981); Lyzenga et al. (2006); Philpot (1989). In order to use the analytical method for mapping the bathymetry, a number of input parameters such as water column, properties of atmosphere and bottom material etc., are needed. Thus, it is very complex and difficult. By comparison empirical method requires only few parameters which are simple and easy for mapping the bathymetry. In the present work, we used a ratio transform algorithm which can retrieve the depth of >25 m in clear water, and also algorithm can predict the depth to certain extend in the turbid water environment which depends on the sediment deposition, varies from location to location. The procedure is adopted using ArcGIS 10.2 Geographical Information System software. This procedure can be used by hydrographers and marine surveyors, for mapping the bathymetry effectively.

2. Ratio Transform Algorithm

Stumpf et al. (2003) developed a ratio transform algorithm to determine the bathymetry of the ocean. The ratio transform algorithm makes use of two bands in order to reduce the number of parameters to determine the bathymetry of the ocean. The algorithm is capable of retrieving depths greater than 25 m in clear water coastal environments and it is also can determine the depth of the turbid coastal environment efficiently. The ratio transform algorithm decreases the bottom most radiance of one band more rapidly with respect to depth, when compared to another band. This leads to, the ratio between the two bands to differ with respect to the depth. A near constant attenuation value will be preserved between the ratio of two bands which is nothing but the difference of the diffuse attenuation coefficient at two different wavelengths; just depending on notion that water column is uniformly mixed. The algorithm can cut down the error coupled with varying radiation in the atmosphere, water column and sea floor, for the reason that both bands are distributed equally. The following equation is used to determine the depth of the near shore coastal area:-

$$z = m_1\left(\frac{\ln\left(L_{obs}\left(Band_i\right)\right)}{\ln\left(L_{obs}\left(Band_j\right)\right)}\right) - m_0 \tag{1}$$

Where, L_{obs} are observed radiance of bands, m_1 and m_o are offset and gain which are determined empirically, and *i* refers to blue band and *j* refers to green band, Z is depth in meter. The advantage of ratio transform algorithm is that it takes very few parameters to determine the depth and it is also easier for marine surveyors to put it into practice.

3. Study area and data used

The present study makes an attempt to determine the bathymetric mapping of the study area at southwest coast of India (roughly 13° 0' 0'' N and 74° 50' 0'' E) where New Mangalore Port Trust (NMPT) area is situated. The study area in Fig.1 is a low energy wave environment with a tidal range of about 0.2 to 1.8 m. For this study Blue, Green and Infrared bands of Landsat 8 (March, 2014) satellite imagery are used. The reason for applying blue and green band in the coastal environment is that radiance in the blue band (450 – 515 nm) decreases more rapidly with depth than radiance in the green band (525 – 600 nm).

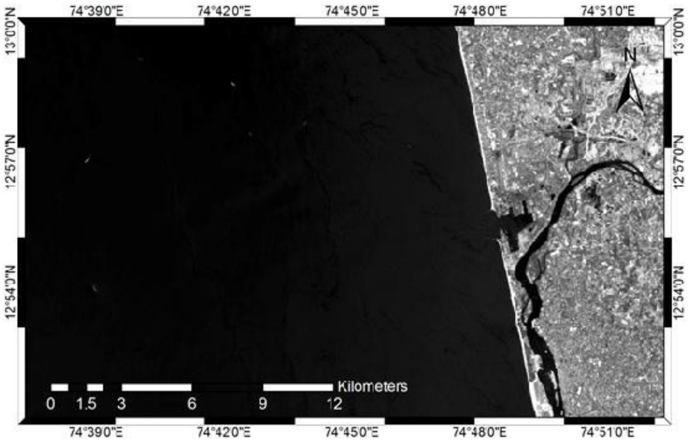


Fig. 1. Imagery of the study area

Generally, light at wavelengths above 700 nm has a very low transmittance in sea water. Therefore water appears dark and the land appears bright. For this reason, the infrared band (845 – 885 nm) is used for distinguishing water from land. In Fig. 2, (a), (b) and (c) show the blue, green and infrared bands of Landsat 8 satellite imagery. Landsat imagery was selected because it is freely available and all imageries are referenced to WGS84. Most importantly hydrographic chart of the same area is used and both satellite imagery and hydrographic charts, are registered correctly. The depth soundings of hydrographic chart are in meters and are referenced to the Mean lower low water (MLLW) tidal datum.

a b c


Fig. 2. Imagery of the study area (a) Blue band, (b) Green band, (c) infrared band

4. Results and discussion

The procedure to obtain the satellite bathymetry includes water separation, spatial filtering, Glint and cloud correction. Fig. 3(a) shows Near infrared (NIR) band of Landsat 8 which is used to separate the water from land, wherein the NIR band reflects water and appears dark and it also reflects the land area and appears bright. As a result, the profile graph of the NIR band over the coastal area has two modes relating to water and land regions. Fig. 3(b) shows the smooth section with low values representing water, whereas the fluctuating high values represents land. In this case the threshold value is 7000 which is used to separate the water from land.

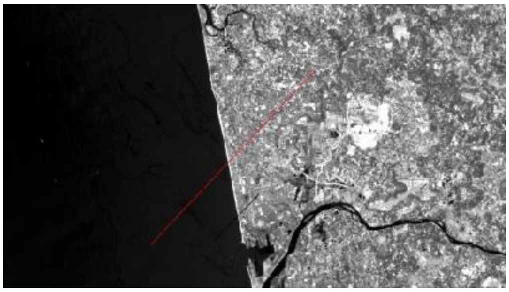
a


Fig. 3. (a) Imagery of study area in NIR band

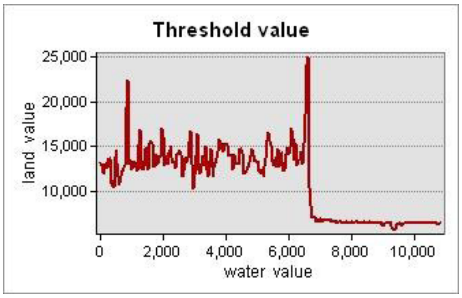
b


Fig. 3. (b) Corresponding Profile graph of NIR band

In order to remove the speckle noise, low pass filter is applied to the both blue and green bands. Threshold value of 7000 is used to remove the land from the blue and green band imagery. The method developed by (Hedley et al., 2005) is used to correct the radiometric contributions from sunglint and clouds of blue and green bands imagery. The reason for sunglint is due to the fact that sun reflects off the surface of the ocean at the same angle similar to that satellite or any other sensor viewing the same surface, because of which smooth ocean water becomes a silvery mirror, while rougher surface waters appear dark. In order to remove the sunglint and cloud, polygon was created over the infrared layer which contains both dark (water) and bright (land) areas. The extracted polygon covers only the water area and the same polygon was next used to extract the water body from the blue and green bands of Landsat 8 imagery. Ratio transform algorithm with radiometrically corrected blue and green band imagery is used to estimate the depth.

Depth is derived by applying the equation (1). Fig (4.a) shows the satellite image which is used to estimate the bathymetry. In Figure (4.a) light blue indicates shallow depth areas and dark blue indicates deep areas. In order to derive the bathymetry data, the hydrographic chart of the same area is overlaid on the satellite image. It is important to note that the hydrographic chart is prepared by using the in-situ data, collected using single beam echo sounders, multi beam echo sounders etc., and it is corrected to MLLW or Lowest Astronomical Tide (LAT). In reality it is difficult to match the water level of satellite image to chart datum. In this work, hydrographic chart is overlaid on the satellite image Fig (4.b). Sounding of this chart is in meters and all the soundings are referenced to the MLLW tidal datum. Depth points in the hydrographic chart and the corresponding pixel values from the satellite image are obtained. The pixel value of the satellite derived bathymetry image is obtained with the reference of hydrographic chart point value, and so there is no need to measure the tidal height during the image acquisition.

The depth range considered in the present work is up to 20 m. From hydrographic chart the depth values are obtained for depth ranging from 1 to 20 m, and each depth series has fractional values ranging from 0.1 to 0.9. For example, 1 m depth series has depth values from 1.1 m, 1.2 m, etc……up to 1.9 m. For each depth value of hydrographic chart, corresponding pixel value from Satellite derived bathymetry (SDB) image is obtained and averaged and the same process is continued for obtaining the remaining depth values. In order to validate the model, the statistical index (R^2) is computed between the algorithm derived value and the hydrographic chart sounding. Fig. (5.a) shows R^2 of 0.8781 between the satellite derived bathymetry value (SDBV) versus hydrographic chart value (HGCV). The plotted data shows a root mean square error (RMSE) of 0.001708 pixels and a mean absolute error (MAE) of 0.001415 pixels (see Table 1). The parameters such as mo and m1 is obtained from the scatterplot Fig.(5.a) where mo is 0.0008 and m1 is 1.0057, further the value of mo and m1 is adopted to plot the range of depth. Fig (5.b) shows the range of depths in the New Mangalore Port harbour area and also covers the adjoining ocean. The whole of approach channel area is always maintained at 15.4 m by the port authorities and the ratio-transform algorithm depth values obtained are also found to be nearly 15.4 m, and hence the validation of the algorithm.

a

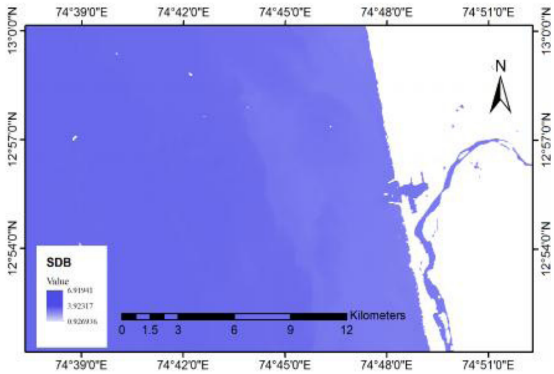


Fig. 4. (a) Satellite derived bathymetry (SDB)

b

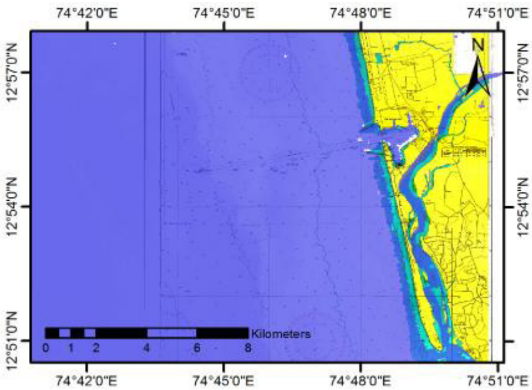


Fig. 4.(b) Hydrographic chart overlaid on SDB

Table 1. Statistical Indices value of validating the model

Statistical Indices value	R^2	RMSE (pixels)	MAE (pixels)
Ratio-transform algorithm	0.8781	0.001708	0.001415

a

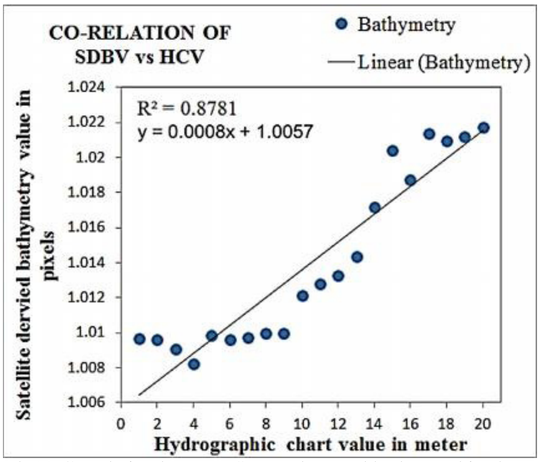


Fig.5. (a) Correlation between SDB values and hydrographic chart values

b

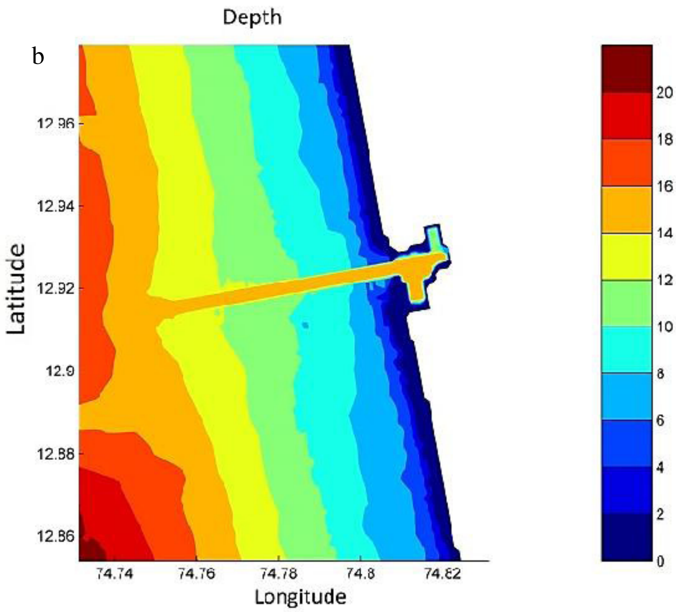


Fig. 5. (b) Range of depths in the study area

5. Conclusions

Statistical indices obtained in the present work indicate that the ratio-transform algorithm can retrieve depths up to 20 m. The procedure used for deriving the satellite bathymetry can be used by the marine surveyors and hydrographic officers. From a practical point of view, this procedure is convenient as a tool for examining near shore coastal area before a high resolution hydrographic survey is carried out by using expensive instrument such as Multi-beam echo sounder etc. By using the results of this tool, marine surveyors can assess the current amount of change in depth and if a weaker R^2 value is observed, it necessitates the update of high resolution hydrographic chart to the existing one. To derive the bathymetry using satellite imagery, environmental conditions such as water clarity, cloud cover, a sunglint is needed to be considered that could degrade the accuracy of estimated depth.

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7. References

Hedley, J.D., Harborne, a. R., Mumby, P.J., 2005. Technical note: Simple and robust removal of sun glint for mapping shallow□water benthos. Int. J. Remote Sens. 26, 2107–2112. doi:10.1080/01431160500034086

Lyzenga, D.R., Malinas, N.P., Tanis, F.J., 2006. Multispectral bathymetry using a simple physically based algorithm. IEEE Trans. Geosci. Remote Sens. 44, 2251–2259. doi:10.1109/TGRS.2006.872909

Philpot, W.D., 1989. Bathymetric mapping with passive multispectral imagery. Appl. Opt. 28, 1569–1578. doi:10.1364/AO.28.001569

R.Lyzenga, D., 1981. Remote sensing of bottom reflecatnce and water attenuation parameters in shallow water using aircarft and Landsat data. Int. J. Remote Sens. 2, 71–82.

R.Lyzenga, D., 1978. Passive remote sening technique for mapping water depth. Appl. Opt. 17, 379–383.

Stumpf, R.P., Holderied, K., Sinclair, M., 2003. Determination of water depth with high-resolution satellite imagery over variable bottom types. Limonology Oceanogr. 48, 547–556. doi:10.4319/lo.2003.48.1_part_2.0547

Su, H., Liu, H., Heyman, W.D., 2008. Automated Derivation of Bathymetric Information from Multi-Spectral Satellite Imagery Using a Non-Linear Inversion Model. Mar. Geod. 31, 281–298. doi:10.1080/01490410802466652.