Topography in intertidal zone by satellite images

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Abstract: Intertidal zone (tidal flat) is a place which is sometimes dry and sometimes wet depending on the tidal rhythm. Direct measurement of topography in the intertidal zone is very difficult to be achieved. The interface between wet and dry parts in the tidal flat, which can be identified from near infrared band of satellite image, is a 'depth contour' which corresponds to the sea level at the time of satellite pass. Aquisition of topography data in tidal flat is possible by combining various techniques such as (1) identification of the interface between wet and dry parts, (2) GCP correction of satellite image, and (3) realtime prediction of sea level elevation at the time of satellite pass. The algorithm was successfully applied in obtaining topography (bathymetry) data in the intertidal zone of Asan Bay in the west coast of Korea from 26 satellite images. The method is expected to be very efficient in making bathymetry data base in the western and southern parts of Korea where tidal flats are well developed in wide regions.

Keywords: Bathymetry, Topography, Intertidal zone. Tidal flat, Near infrared

1. Introduction

Intertidal zone is a place which is dry at low tide and wet at high tide. Bathymetry observation in intertidal zone is practically very difficult to be achieved. Shallowness of water in intertidal zone permits shipboard echo sounding only at high tide. Land based topography observation is possible during low tide, but muddy ground condition make direct *in situ* observation very difficult.

Stereoscopic image matching of aerial photography is one of the common practices in determination of land topography (Wolf and Dewitt, 2000; Gensen 2000). But that method is difficult to be applied in the intertidal zone, mainly due to a lack of land marks in the flat muddy condition. Recently, LIDAR (Light Detection and Ranging) method, in which topography is determined by returning SAR (Synthetic Aperture Radar) signal emitted from the airborne, is considered as a practical method in determining topography in the beach areas (NOAA Coastal Services Center, 1998). But this high cost method is not employed yet in observing intertidal zone topography of Korea.

Topography data in the intertidal zone are needed not only for efficient management of coastal regions but also for precise numerical modelling of coast regions. In most cases. in fact, topography data in the intertidal zone are very rare. In this paper I present a simple and practical method which can be used in a quantitative determination of intertidal zone topography by combining the wet and dry interface data extracted from the satellite image and the tidal water level elevation predicted by harmonic method. The method is employed in construction of 1 second (30m) grid bathymetry data base of Asan Bay in the western coast of Korea.

2. Method

Rise and fall of sea surface elevation associated with tidal motion produce periodic forward marching and backward retrieval of the interface between the wet water part and dry land part in the tidal flat. The interface between dry and wet parts is a contour of equal height, of which value can be quantitatively determined by tide prediction method. The geographic position of any point in the wet and dry interface can be determined uniquely by using affine transform coefficients derived from the pixel coordinates and geographic positions at more than 3 GCP's (ground control points). The tidal elevation at the time of satellite pass can be predicted quite precisely by adjusting the relative magnitude and time lag (phase shift) of tidal elevation at the point of interest with respect to the predicted tide at the tide station (Kang 2002).

The wet and dry parts in tidal flat is clearly distinguished in the infrared (NIR) band of satellite image, although they are not clearly identified in the visible bands. Available satellite images with NIR band include Landsat TM (spatial resolution 30m), JERS OPS (spatial resolution 24m), SPOT MultiBand (spatial resolution 20m), Adeos AVNIR (spatial resolution 16m), Kitsat-3 (spatial resolution 14m) and IKONOS MultiBand (spatial resolution 1m). In a tidal flat of 3km wide with tidal range of 4m, which is typical order in the western and southern coast of Korea, the topography height difference across 30m distance is approximately 4cm. This figure is less than the required accuracy of 10m in bathymetry observation. The method presented in this paper can be effectively used in widely extended tidal flats.

Quantitative topography data in the intertidal zone can be obtained from satellite image by combining following three techniques: (1) Identification of the dry and wet interface from NIR band of satellite image, (2) Geometric coordinates of satellite image pixels using GCP correction, and (3) Prediction of sea surface elevation by tide at the time of satellite pass. Since a single image can produce 'one' coastline only, we need many tens of images to produce topography data base in the tidal flat.

(1) Identification of dry/wet interface from satellite image.

The interface between sea water part and exposed dry part in tidal flat can be clearly identified from the NIR band of satellite images. For 256 level images, typical digital number (DN) of NIR band image over the sea surface is only about 10, that over the exposed tidal flat is about 80, and that on dry land never covered by sea water is about 200. The dry/wet interface is identified by the interface between dry/wet binary image, which can be made by assigning a suitable threshold DN, for example 60, that distinguish sea water and exposed parts in the tidal flat.

The dry/wet interface data obtained by this method may include some 'false' data which are not true 'depth contour' associated with tidal elevation. Examples of 'false' interfaces are the boundaries of clouds, ships on the sea, artificial aquaculture structure, coastal structures like pier, clipped coastline, tide pools in intertidal zone, etc. Those 'false' dry/wet boundaries must be excluded by masking those regions.

(2) GCP correction of dry/wet interface

We need geographic longitude and latitude values (u, v) from pixel coordinates (x, y) at wet/dry interface. This can be done by linear affine transform

$$u(x,y)=a_1x+a_2x+a_3$$

$$v(x,y)=b_1x+b_2y+b_3$$

or quasi-linear affine tranform

$$u(x,y)=a_1xy+a_2x+a_3y+a_4$$

$$v(x,y)=b_1xy+b_2x+b_3y+b_4$$

The affine transform coefficients (a1,..., b1, ...) are obtained by the least squares method that minimizes the error between 'actual' position and the 'computed' position by above equations at all GCP's. Required number of GCP data is 3 or more for the case of linear transform and 4 or more for quasi-linear transform. The geographic longitude and latitude at GCP are obtained from digital charts published by National Oceanography Research Institute.

Since the meridional lines converge as going to poleward, zonal distance associated with a unit longitude is different from latitude to latitude. The transform from pixel coordinates to geographic longitude and latitude is acceptable if the study area is relatively narrow, When the study area is wide, for example, wider than 40 km, the pixel coordinates should be transformed first to local Gauss-Krueger Projection (TM), and then the TM position should be converted to longitude and latitude data.

(3) Real time prediction of sea surface elevation

Realtime tides at standard tide stations can be predicted by harmonic prediction method. Typically 60 harmonic constants are employed in realtime tide prediction, and the accuracy of tide prediction is of an order of a few centimeters. During special events such as storm surge or Tsunami, the predicted tidal elevations may differ significantly from the actual ones. However, for the days of cloud free satellite images, which are actually used in our study, prediction of sea level elevation can be made quite accurately.

The tidal waves propagates as tidal waves, and the tidal elevation at each pixel along the dry/wet interface is somewhat different from the tidal elevation at the standard tide station. However, by combining the numerical model parameters and the realtime tide at the tide station, the tide at each pixel on the wet/dry interface at the satellite pass time can be predicted quite accurately, for example, by using CHARRY (Current by Harmonic Response to Reference Yardstick) algorithm (Kang, 1997).

3. Applications

Our method is applied in a construction of bathymetry data base of Asan Bay in the western coast of Korea. Extraction of topography data from the satellites was done by Program TTR (TTR is an abbreviation of Tidal-zone Topography by Remote-sensing) which is made by the author. From 26 satellite images (9 Landsat TM images, 12 SPOT multi-spectral images, 3 JERS OPS images and 2 KitSat-3 images), I extracted approximately 200,000 topography data in the intertidal zone. By combining this data set with 400,000 bathymetry sounding data by echo sounder and multi-beam sounder provided by National Oceanography Research Center, I made 1 second (30m) grid bathymetry data base of the Asan Bay. The random point data are interpolated to grid data by employing quintic polynomial interpolation method (Akima 1978a, 1978b; Preusser 1984a, 1984b). Fig. 1 shows an example of the topography contours extracted from the satellite images in the Namyang Bay in the northwestern part of Asan Bay.

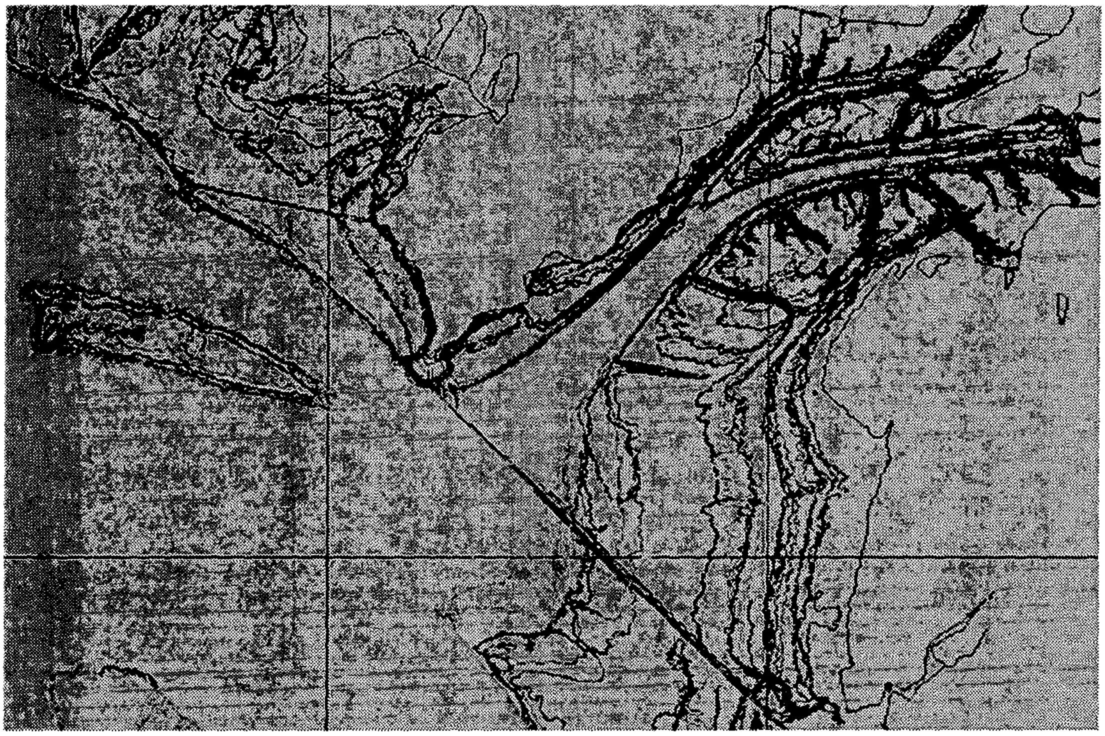

Fig. 1. Depth contours in the northwestern part of Asan Bay extracted from NIR band of satellite images.

4. Discussion and Conclusions

Aquisition of tidal flat topography is possible by combining wet/dry interface data extracted from the satellite images and the realtime tide prediction data at the satellite pass time. However, the 'depth contours' data available from satellite images are limited to 'intermediate' part of tidal flats. Since the occurrence of extreme low tide or extreme high tide is very rare, depth contours at extreme lower parts and upper parts of tidal flat are very difficult to be obtained from satellite images. Land based observations are needed to get topography in the upper part of tidal flat. On the other hand, the shipboard soundings are necessary to get bathymatry data in the lower part of tidal flats.

The spatial resolution of satellite images limits the applicability of the method described in this paper. Our method is suitable for topography data in 'wide extended' tidal flats, but not suitable in 'narrow extended' tidal flats. Our method can be successfully applied in obtaining topography data in the tidal flats in the western and southern parts of Korea, where tidal flats extends even more than 5 km.

Detail topography data are very useful for the safety in coastal region, accurate numerical modelling, coastal oil spill problems, naval landing operation, etc. Once detail topography data are available, with an aid of realtime tide prediction, one can simulate the realtime march and retreat of 'actual' coastline in cybernetic space.

Acknowledgements: Many satellite images used for this study were provided by Mr. Oksoo Kim, Ministry of Marine Affairs and Fisheries, Drs. B. K. Kim and Y. S. Suh, National Fisheries Research and Development Institute, Prof. B. H. Choi, SungGyunGwan University, and Dr. Moonjin Lee, Korea Ocean Research and Development Institute. Those helps are gratefully acknowledged.

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