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Shoreline extraction using satellite imagery

a. Introduction

The coastal area is a highly dynamic environment with many physical processes, such as tidal inundation, sea level rise, land subsidence, and erosion-sedimentation. Those processes play an important role for the shoreline change and coastal landscape development. Multi-years shoreline mapping is considered a valuable task for coastal monitoring and assessment. A shoreline is defined as the line of contact between land and a body of water. It is easy to define but difficult to capture, since the water level is always changing. Therefore, a problem exists in the mapping community because different public or private entities have compiled and published shoreline delineations that are based on different shoreline definitions. This has created confusion and uncertainty for those who use shoreline information daily for decision making, resource planning emergency preparedness etc. In USA for example, NOAA use the tide-coordinated shoreline, which is the shoreline extracted from a specific tide water level. The MLLW (Mean Lower Low Water) and MHW (Mean High Water) are used in this way to map shorelines that can be georeferenced. Both the MLLW and MHW are calculated from averages over a period of 18.6 lunar years (Li et al., 2001). In contrast, the U.S. Geological Survey (USGS) compiles shoreline data for the 1:24.000-scale topographic base map series from digital orthophoto quadrangles created from photographs that are not tide coordinated, thereby making the shoreline a snapshot in time (Scott et al., 2003). It is therefore obvious that since shoreline has a dynamic nature, its definition, mapping and monitoring are complicated tasks.

b. Background

Different approaches to shoreline mapping and change detection have been used in the past. Traditional shoreline mapping in small areas is carried out using conventional field surveying methods. The method used today by the American National Geodetic Survey to delineate the shoreline is analytical stereo photogrammetry using tide-coordinated aerial photography controlled by kinematic GPS techniques (Di et al., 2003). Land vehicle-based mobile mapping technology has been proposed to trace water marks along a shoreline using GPS receivers and a beach vehicle. Lidar depth data have also been used to map shorelines (Shaw and Allen, 1995; Li, 1997).

Automatic extraction of shoreline features from aerial photos has been investigated using neural networks and image processing techniques (Ryan et al., 1991). Photogrammetric techniques have been employed to map the tide-coordinated shoreline from the aerial images that are taken when the water level reaches the desired level. Aerial photographs taken at these water levels are more expensive to obtain than satellite imagery.

Besides aerial imagery, spaceborn radar and especially Synthetic Aperture Radar (SAR) has proven a valuable tool for coastal monitoring. SAR imagery has also been used to extract shorelines at various geographic locations (Erteza, 1998; Chen and Shyu, 1998; Trebossen et al., 2005; Wu and Lee, 2007). SAR is a very promised technology, especially for Europe since the European Space Agency (ESA) is recognized as a world leader in SAR missions (ERS1, ERS2, Envisat, GMES-Sentinel-1).

In recent years, optical satellite remote sensing data has been used in automatic or semi-automatic shoreline extraction and mapping. Braud and Feng (1998) evaluated threshold level slicing and multi-spectral image classification techniques for detection and delineation of the Louisiana shoreline from 30-meter resolution Landsat Thematic Mapper (TM) imagery. They found that thresholding TM Band 5 was the most reliable methodology. Frazier and Page (2000) quantitatively analyzed the classification accuracy of water body detection and delineation from Landsat TM data in the Wagga region in Australia. Their experiments indicated that the density slicing of TM Band 5 achieved an overall accuracy of 96.9 percent, which is as successful as the 6-band maximum likelihood classification. Scott et al. (2003) proposed a semi-automated method for objectively interpreting and extracting the land-water interface has been devised and used successfully to generate multiple shoreline data for the test States of Louisiana and Delaware. This method was based on the application of Tasseled Cap transformation coefficients derived by the EROS Data Center for ETM+ data as described by Huang et al. (2002). The Tasseled Cap transformation was chosen over other methods primarily because of the objective and consistent manner in which it classifies pixels and because its use allowed the creation of other useful raster byproduct files. In operation, the Tasseled Cap transformation recombined spectral information of the 6 ETM+ bands into 3 principal view components through the use of coefficients derived by sampling known land cover spectral characteristics. Of the three principal view components created, i.e., Brightness, Greenness, and Wetness, the Wetness component is exploited to differentiate land from water. Zakariya et al. (2006) tried to detect shoreline changes for the Terengganu river mouth and related coastal area. Landsat data were used together with GIS capability to determine shoreline, sandy area and the changes occur specially on sediment movement from 1996 to 2002. RGB to IHS imagery conversion analysis ISODATA (Iterative Self-Organizing Data Analysis) classification were employed. Liu and Jezek (2004), as well as Karantzalos and Argialas (2007) automated extraction of coastline from satellite imagery by canny edge detection using digital number (DN) threshold.

Li et al. (2001) compared shorelines of the same area extracted using different techniques, evaluated their differences and discussed the causes of possible shoreline changes. The different shoreline products had been generated using different techniques: by digitizing from aerial orthophotos, intersecting a digital water surface with a coastal terrain model and extraction from stereo satellite images. In addition, existing shorelines digitized from USGS maps and NOAA T-Sheets were included in their analysis.

With the development of remote sensing technology, satellites can capture high resolution imagery with the capability of producing stereo imagery. The new generation of very high spatial resolution satellite imaging systems, such as IKONOS and QuickBird, opens a new era of earth observation and digital mapping. They provide not only high-resolution and multi-spectral data, but also the capability for stereo mapping. Because of their high resolution and their short revisit rate (~3 days), IKONOS and QuickBird satellite images are very valuable for shoreline mapping and change detection, therefore their data have been used in several past studies. Wang et al. (2003) investigated a novel approach for automatic extraction of shoreline from IKONOS images using a mean shift segmentation algorithm. Di et al. (2003) investigated a novel approach for automatic extraction of shorelines from IKONOS imagery. 4 m and 1 m resolution IKONOS images along the Lake Erie shore were used. In the first step the images were segmented into homogeneous regions by mean shift segmentation. Then, the major water body was identified and an initial shoreline was generated. The final shoreline was obtained by local refinement within the boundaries of the candidate regions adjacent to the initial shoreline. Li et al (2003) used IKONOS stereo imagery in shoreline extraction. They presented the results of an experiment in which they attempted to improve IKONOS Rational Functions (RF) for a better ground accuracy and to employ the improved RF for 3-D shoreline extraction using 1-meter panchromatic stereo images in a Lake Erie coastal area. In this method, a 2D shoreline is extracted by manual digitizing on one IKONOS image; then corresponding shoreline points on the other image of the stereo pair are automatically extracted by image matching. The 3D shoreline is computed using photogrammetric triangulation. Chalabi et al. (2006) had used pixel-based segmentation on IKONOS image using DN threshold. The partition of the land and sea boundary was done using pseudo color which exhibits a strong contrast between land and water features.

Shoreline change is considered one of the most dynamic processes in coastal area. It has become important to map the shoreline change as an input data for coastal hazard assessment. There are many change detection techniques currently in use including visual interpretation, spectral-value-based technique (differencing, image regression, DN value analysis), multi-data composites, and change vector analysis. Visual interpretation of multi-temporal images for coastal monitoring was presented by Mazian et al. (1989) and Elkoushy and Tolba (2004). Bagli and Soille (2003) analyzed DN value using slicing operation for change monitoring. In addition, Whithe and El Asmar (1999) introduced an algorithm function and DN analysis to deviate the water from the land. The DN value analysis has also been applied on Landsat images, e.g. by Frazier and Page (2000) and Marfai (2003). Fromard et al. (2004) identified coastal changes that took place over the last 50 years, and related them to natural processes of turnover and replenishment of mangrove forests. They used a combination of remote sensing techniques (aerial photographs and SPOT satellite images) and field surveys in the area of the Sinnamary Estuary, French Guiana. Mills et al. (2005) introduced the integration of the geomatics techniques to form accurate representations of the coastline. A highly accurate Digital Elevation Model (DEM), created using kinematics GPS, was used as control to orientate surfaces derived from the relative orientation stage of photogrammetry processing. Mostafa and Soussa (2006) have applied GIS and remote sensing technique to monitor the lake of Nasser including the shoreline dynamic. Three satellite Landsat images for Nasser Lake was available in a time series (1984, 1996, and 2001). Topography map of scale 1:50,000 that is suitable to the resolution of Landsat images, was used for developing DEM. Chalabi et al. (2006) assessed multi-data sources for monitoring shoreline in Kuala Terengganu, Malaysia using IKONOS and aerial photographs. Results of time series data were combined each other showing spatial change of shoreline. Marfai et al. (2007) illustrated the shoreline dynamic in a coastal area of Semarang-Indonesia using multisources spatial data. In spite of the technique and approach to shoreline monitoring and delineation, no single method has been implemented that is free from major disadvantages.

Therefore, shorelines of the same area may be extracted at different times using satellite data and represent changes appeared in difference periods illustrated as differences among them. There are two possible interpretations of the shoreline differences. One is that the shoreline in deed changed in the real world. The other possibility is that the differences are introduced by shoreline mapping errors. The accuracy of the shoreline derived from 1 meter IKONOS imagery should be about 2 - 4m (Zhou and Li 2000; Li et al., 2001, Grodecki and Dial, 2003), considering the fact that the accuracy of 3D ground control points (GCPs) reaches 2 – 3 m, with GCPs and the accuracy of identifying and locating conjugate shoreline points is about 1.5 pixels (1-2m). An optimistic estimation of the shoreline accuracy derived from the 4-meter IKONOS images in this specific case is about 8.5m (Li et al., 2001).

In most of the aforementioned methods, the shoreline extraction using IKONOS orthoimagery is based on land cover classification to discriminate the pixels corresponding to water bodies from those corresponding to land. Following, the resulted thematic image is converted to vector coverage, usually a polygon shapefile (ESRI, 2005) containing the polygons corresponding to each class. The shoreline is finally extracted from the polygon that corresponds to water by employing automatic or semi-automatic GIS procedures. Thus, the accuracy of the image orthorectification, as well as the accuracy of the image classification are the most important factors affecting the accuracy of the extracted shoreline. The orthorectification accuracy has discussed above. Concerning classification accuracy, it depends on the spatial, spectral and radiometric resolution of the image, as well as on the classification method. Numerous studies have been carried out using satellite images to extract land cover types (Congalton, 1991; Ridd and Liu, 1998; Martin et al., 1988; Gong and Howarth, 1990; Chrysoulakis 2003; Gallego, 2004). The majority of the past studies rely on remote sensing data to classify land cover types using either raw DN or calibrated radiance values. However, if very high spatial resolution data such as IKONOS images are used, the land cover classification of coastal areas may be problematic because of the heterogeneity and small spatial size of the surface materials, which leads to significant sub-pixel mixing (Foody, 2000; Kontoes et al., 2000). Therefore, the spatial context should be taken into account in image classification and object oriented algorithms should be used. Improvements in the accuracy of classification have been achieved using a variety of sophisticated approaches including the use of neural networks (Berberoglu et al., 2000), fuzzy logic (Bastin, 1997; Zang and Foody 1998;), texture analysis (Stuckens et al., 2000), machine learning (VLS, 2007) and incorporation of ancillary spatial data in the classification scheme (Harris and Ventura, 1995; Vogelmann et al, 1998, Stefanov et al., 2001).

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