Coastal Mapping and Change Detection Using High-Resolution IKONOS Satellite Imagery

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Abstract

Shoreline mapping and shoreline change detection are critical in many coastal zone applications. This paper presents results of the semi-automatic mapping of a coastal area of Lake Erie using 4-meter resolution multispectral (XS) and 1-meter resolution panchromatic (Pan) IKONOS Geo stereo images. An overview of the geometric processing of IKONOS imagery is presented. Then, the latest results of our IKONOS geopositioning accuracy improvement efforts are reported. Subsequently, methods and results of automatic generation of a Digital Elevation Model (DEM) and an orthoimage are outlined. Finally, a novel approach for the automatic extraction of a 3D shoreline from IKONOS images is described. Test results show that the proposed approach is capable of extracting shorelines from IKONOS images with little human interaction. The accuracies of the extracted shorelines from 4m XS and 1m Pan stereo images are estimated to be 8.5m and 2-3m, respectively.

1. Introduction

Shoreline mapping and shoreline change detection are critical for safe navigation, coastal resource management, coastal environmental protection, and sustainable coastal development and planning. Shoreline mapping techniques have developed from conventional field survey methods through expensive, airborne coastal mapping techniques to new automatic or semi-automatic processes. Some of the new techniques that have been applied to shoreline mapping include neural nets and image processing techniques for the automatic extraction of shoreline features, land vehicle-based mobile mapping technology and Light Detection and Ranging (LIDAR) for water depth data acquisition. More data, especially satellite remote sensing data and SAR imagery, are now available for automatic or semi-automatic shoreline extraction and mapping. The new generation of high-resolution and multispectral IKONOS and QuickBird imagery has opened a new era of digital stereo mapping. Their high resolution and short revisit rate (approximately 3 days) make the images very valuable for shoreline mapping and coastal change detection. The nominal absolute positioning accuracy (root mean square error, or RMSE) of the 1m and 4m IKONOS Geo products is 25m. Highly accurate products, such as IKONOS Precision and IKONOS Precision Plus, are much more expensive than the less accurate Geo product. It is attractive to find a way to use the low-cost IKONOS Geo product to produce highly accurate outcomes comparable to those produced using the more expensive Precision and Precision Plus products. Currently, the orientation information of IKONOS images is available only in the form of a so-called Rational Function (RF) model, which is also called the Rational Polynomial Camera (RPC) model. Reports have been made on a number of investigations into the photogrammetry processing of IKONOS imagery and improvement of the accuracy of the RF model and IKONOS products (Li, 1998; Zhou and Li, 2000; Li et al., 2002; Grodecki and Dial, 2001; Grodecki and Dial, 2003; Di et al., 2003; Fraser et al., 2003; Toutin, 2003).

This paper presents the results of the semi-automatic mapping of a coastal area of Lake Erie using 4-meter resolution multispectral (XS) and 1-meter resolution panchromatic (Pan) IKONOS Geo stereo images. An overview of the geometric processing of IKONOS imagery is presented. We also report on the latest results of our IKONOS geopositioning accuracy improvement efforts. Methods and results from the automatic generation of a Digital Elevation Model (DEM) and an orthoimage are outlined. Finally, a novel approach for the automatic extraction of 3D shorelines from IKONOS images is described.

2. IKONOS Image Data

IKONOS images were taken along the southern shore of Lake Erie covering a study area about 11km shoreline, with an elevation ranging from 170m to 230m. A 4m XS image of the study area was acquired on October 30, 2000. The image was geometrically rectified and map-projected to UTM projection. Two stereo pairs of 1m IKONOS Geo Pan images were acquired on March 19, 2001. Rational Function Coefficients (RFCs) of each image were supplied by Space Imaging, Inc.

Ten high-precision GPS control points were surveyed in this area. In addition, 57 aero-triangulated points were computed and used as ground control points (GCPs) and checkpoints in the assessment and improvement of geometric accuracy.

3. Geometric Processing of IKONOS Imagery

Currently, different techniques are proposed to improve the accuracy of the RF model of IKONOS products. A general discussion of the RF model can be found in Whiteside (1997) and in Tao and Hu (2001). Grodecki and Dial (2003) found that multiple physical model parameters have the same net effects on the object-image relationship. They recommended using simple adjustment models, either Offset, Scale & Offset, or Affine. With these models they achieved 1-2m accuracy. Fraser et al. (2003) made bias compensation in RFs with 1 GCP, and achieved sub-meter accuracy. Toutin (2003) used a parametric model for Pan and XS IKONOS image geometric processing. Accuracies achieved were 1-2m or 2-4m, depending on the quality of the GCPs. Li et al. (2003) used two approaches to improve the IKONOS RF for better ground accuracy: refining the RFCs using the GCPs or rectifying the ground coordinates from the vendor-provided Rational Functions. Both methods were able to achieve an accuracy of 2-4m, but the second method appeared to have superior results. A "RF + 3D Affine" model defined in object space was found to achieve a 1-2m accuracy level.

Based on the above-mentioned as well as previous experiments, we systematically investigated the impact of adjustment models and GCP distribution on the geopositioning accuracy of 1m Pan IKONOS. Four models (Offset, Scale & Offset, Affine, and 2nd-order Polynomial) defined both in the image space and in the object space were tested. Different numbers and distributions of GCPs for each model were also compared. Experimental results indicate that the number, accuracy and distribution of GCPs greatly affect the results of the adjustment. Adjustment models defined in the object space and in the image space did not show significant differences in accuracy improvement. Using the Offset model with only one GCP is the simplest way to adjust the coordinates, but the resulting accuracy depends very much on the accuracy of the GCP and has no apparent relationship its location. Both the Scale & Offset model (with 4 to 6 GCPs) and the Affine model (with 6 or more GCPs) produced stable and satisfactory results at the level of 1-2m. The Scale & Offset and Affine were both found to be effective in eliminating the systematic errors found in the vendor-provided RFCs and in significantly improving the accuracy of 3D geopositioning. Therefore, they are recommended for relatively flat areas like the test area. Second- or higher-order polynomial models are highly sensitive to height, therefore they may be more appropriate for mountainous areas. Detailed results of the experiment will be reported in a forthcoming paper.

4. Coastal Area Mapping from IKONOS Imagery

4.1 DEM and Orthoimage Generation

A detailed description of the process of automatic DEM and orthoimage generation can be found in Di et al. (2002). The DEM is automatically generated by a chain of processes: area-based image matching, ground point calculation, outlier elimination, TIN construction, and interpolation. Image matching is the key step in DEM generation. It is performed by area-based matching using normalized correlation coefficients. Following DEM generation, an orthoimage is produced using 1m IKONOS images and the DEM with 1m spacing in the same coordinate system. The accuracy of DEM and orthoimage reached approximately 2m in planimetry and 3m in height.

4.2 Automatic 3D Shoreline Extraction

In our previous work, 3D shorelines were extracted in 3 steps. First, 2D shorelines were obtained through manual digitization in one image of a Pan IKONOS stereo pair. Then, automatic matching was performed in the other image of that pair. Finally, the 3D ground coordinates of the shoreline points were triangulated using the "RF + 3D Affine" model.

In our current work, we have investigated a novel approach for the automatic extraction of 2D shorelines from XS and Pan IKONOS images. This approach has been developed to replace manual digitization. It is based on mean shift segmentation, major water body identification, initial shoreline extraction, and shoreline refinement. Shoreline refinement is currently accomplished interactively based on the initial shoreline and adjacent candidate polygons obtained from the mean shift segmentation. The remaining steps are automatic. The entire process needs little human interaction and is much more efficient than manual digitizing. After the 2D shoreline (see Figures 1 and 2) is extracted semi-automatically, the remaining steps to extract the 3D shoreline remain the same as in our previous work. We can now update the 3D shoreline extraction method to improve the level of automation. In the future, an automatic shoreline refinement method could be developed using local shape, spectral and texture information.

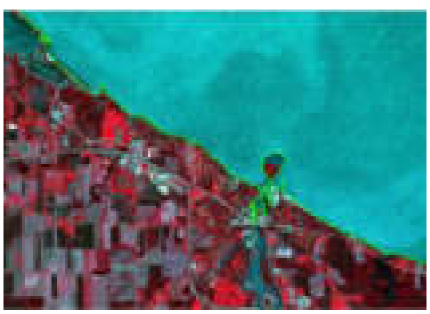

Figure 1. Refined shoreline superimposed on the 4-m resolution XS IKONOS image

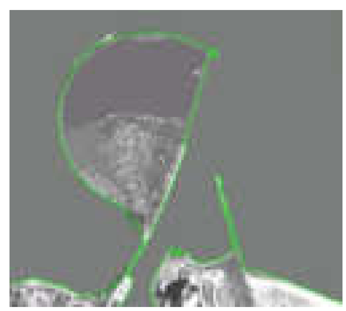

Figure 2. Refined shoreline superimposed on the 1-m resolution Pan IKONOS image

4.3 Accuracy Evaluation

The effect of segmentation on the accuracy of the final 3D shoreline is an interesting issue. After matching, a visual check is needed to ensure that the conjugate shoreline points are correct. By visual checking, the automatically extracted shoreline is found to be at the correct positions in most cases. After shoreline refinement, the resulting 3D shoreline should have an accuracy comparable to a manually digitized shoreline. We estimate the shoreline identification and matching error to be 1-1.5 pixels, and the pointing (digitizing) error on the screen to be 0.5-1 pixel. Based on the 1-2m 3D geopositioning accuracy, the ultimate accuracy of the 3D shoreline is estimated to be 2-3m. A further experiment is needed to quantitatively analyze the accuracy of the automatically extracted shoreline.

The shoreline extracted from the 4m XS imagery is geo-corrected using the same polynomial used in the accuracy improvement experiment. Based on an identification error of 1.5 pixels (6m) and the 1m positioning accuracy after the 2D polynomial geo-correction, the ultimate accuracy is estimated as 8.5m for the 4m XS images.

5. Conclusions

This experiment on accuracy improvement of IKONOS geopositioning has indicated that a simple adjustment model (either the Affine or the Scale & Offset) is effective for elimination of the systematic errors found in vendor-provided RFCs and for improvement of the 3D geopositioning accuracy to a 1-2m level. This level is comparable to that of the much more expensive IKONOS Precision stereo imagery.

A semi-automatic method for the extraction of a shoreline from 1-meter resolution Pan and 4-meter resolution XS images was presented. Our shoreline extraction experiments have demonstrated the effectiveness of our semi-automatic method for processing IKONOS imagery. Fully automated shoreline extraction from remote sensing images is very difficult due to the effects of trees, shadows, coastal structures, and the low contrast between water and land, as well as many other factors. The method presented in this paper, especially the shoreline refinement process, will be improved in the future.

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