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Shoreline extraction using satellite imagery

The IKONOS satellite provides global, accurate, high-resolution imagery for mapping, monitoring, and development. The panchromatic sensor with 82 cm resolution and an 11.3 km wide swath at nadir provides high resolution, intelligence-quality imagery. The multispectral sensor, simultaneously collecting blue, green, red, and near infrared bands with 3.28 m resolution at nadir, provides natural-color imagery for visual interpretation and color-infrared imagery for remote sensing applications. Combining the multispectral imagery with the high resolution panchromatic results in 1-meter color images (pan-sharpen product), which can be afterwards orthorectified. The orthorectification is needed to eliminate the geometric distortions, which will be explained below, so that image features have correct planimetric coordinates. Quantitative estimations such as shoreline detection are performed using orthorectified images.

Apart from the different techniques that can be applied for shoreline extraction and monitoring from high resolution satellite images, the processing chain consists of the following basic steps:

- acquisition of images and pre-processing;
- acquisition of the GCP's with image coordinates and map coordinates;
- computation of the unknown parameters of the mathematical functions used for the geometric correction model;
- image orthorectification using an appropriate DEM;
- automatic, semi-automatic or manual shoreline extraction from the orthorectified imagery;
- monitor the shoreline changes by repeating the above steps at predefined time periods and compare the relative positions of the extracted shorelines.

Thus, before the application of any algorithm for automatic extraction of shoreline from multispectral satellite images, these images should be othorectified to take into account the geometric distortions during the image acquisition, as well as the effect of topography. Each image acquisition system produces unique geometric distortions in its raw images and consequently the geometry of these images does not correspond to the terrain or of course to a specific map projection. Obviously, the geometric distortions vary considerably with different factors such as the platform, the sensor and also the total field of view. However, as it has been described by Toutin (2004), it is possible to make general categorizations of these distortions. The sources of distortion can be grouped into two broad categories: the observer or the acquisition system (platform, imaging sensor and other measuring instruments, such as gyroscope, stellar sensors, etc) and the observed (atmosphere and Earth). In addition to these distortions, the deformations related to the map projection have to be taken into account because the terrain and most GIS end-user applications are generally represented and performed respectively in a topographic space and not in the geoid or a referenced ellipsoid. Most of these geometric distortions are predictable or systematic and generally well understood. Some of these distortions, especially those related to the instrumentation, are generally corrected at ground receiving stations or by image vendors. Others, for example those related to the atmosphere, are not taken into account and corrected because they are specific to each acquisition time and location and information on the atmosphere is rarely available. The remaining geometric distortions require models and mathematical functions to perform geometric corrections of imagery: either through 2D/3D empirical models (such as 2D/3D polynomial or 3D RF) or with rigorous 2D/3D physical and deterministic models. With 2D/3D physical models, which reflect the physical reality of the viewing geometry (platform, sensor, Earth and sometimes map projection), geometric correction can be performed step-by-step with a mathematical function for each distortion/deformation, or simultaneously with a combined mathematical function.

2D/3D physical functions used to perform the geometric correction differ, depending on the sensor, the platform and its image acquisition geometry (Toutin, 2004):

- instantaneous acquisition systems, such as photogrammetric cameras, Metric Camera or Large Format Camera;
- rotating or oscillating scanning mirrors, such as Landsat-MSS, TM and ETM+;
- push-broom scanners, such as SPOT-HRV, IRS-1C/D, IKONOS and Quickbird; and
- SAR sensors, such as JERS, ERS-1/2, RADARSAT-1/2 and Envisat.

Whatever the geometric model used, even with the RF some GCPs have to be acquired to compute/refine the parameters of the mathematical functions in order to obtain a cartographic standard accuracy. Generally, an iterative least-square adjustment process is applied when more GCPs than the minimum number required by the model (as a function of unknown parameters) are used. The number of GCPs is a function of different conditions: the method of collection, sensor type and resolution, image spacing, geometric model, study site, physical environment, GCP definition and accuracy and the final expected accuracy. The aerial triangulation method has been developed and applied with different optical and radar satellite data using 3D physical models (Toutin 2003a, b), as well as with IKONOS data using 3D RF models (Fraser et al. 2002a, b). All model parameters of each image/strip are determined by a common least-squares adjustment so that the individual models are properly tied in and an entire block is optimally oriented in relation to the GCPs.

As it has been already motioned, shoreline extraction needs orthorectified images. To rectify the original image into a map image, there are two processing operations:

- a geometric operation to compute the cell coordinates in the original image for each map image cell, eliminating the geometric distortions as previously explained; and

- a radiometric operation to compute the intensity value or DN of the map image cell as a function of the intensity values of original image cells that surround the previously-computed position of the map image cell.

The geometric operation requires the observation equations of the geometric model with the previously computed unknowns, and sometimes elevation information. 3D models take into account elevation distortion DEM is thus needed to create precise orthorectified images. DEM impact on the orthorectification process, both in terms of elevation accuracy for the positioning accuracy and of grid spacing for the level of details. This last aspect is more important with high-resolution images because a poor grid spacing when compared to the image spacing could generate artefacts for linear features such as shorelines. For any map coordinates (x, y), with the z elevation extracted from a DEM when 3D models are used, the original image coordinates (column and line) is computed from the two resolved equations of the model. However, the computed image coordinates of the map image coordinates will not directly overlay in the original image; in other words, the column and line computed values will rarely, if ever, be integer values. Since the computed coordinate values in the original image are not integers, one must compute the DN to be assigned to the map image cell. In order to do this, the radiometric operation uses a resampling kernel applied to original image cells: either the DN of the closest cell (called nearest neighbor resampling) or a specific interpolation or deconvolution algorithm using the DNs of surrounding cells (Toutin, 2004).

In order to accurately create or extract geographic information from raw IKONOS imagery, the Image Geometry Model (IGM) must accompany the imagery. The IGM consists of several metadata files which contain RPCs (rational polynomial coefficients). The RPCs are a series of coefficients that describe the relationship between the image as it existed when captured and the Earth’s surface. Although they do not describe sensor parameters explicitly, RF are simple to implement and perform transformations very rapidly. With the availability of RPCs, the IKONOS interior and exterior orientation are very accurate. Therefore IKONOS imagery can be orthorectified if the IGM, an accurate DEM and some GCPs are available by employing any photogrametric software such as Orthoengine (PCI, 2003) or Leica Photogrammetry Suite (Leica, 2005).

The next step for shoreline extraction is the water-land separation; therefore the orthorectified image should be classified or a polygon corresponding to water (or land) area should be extracted. Taking into account the aforementioned land cover mapping constraints for very high spatial resolution satellite data, a machine learning classifier approach seems the best solution for IKONOS multispectral image classification. This type of classifier uses an inductive learning algorithm to generate production rules from training data. As with a neural network, there are several advantages to using a machine-learning approach. Since ancillary data layers may be used to help improve discrimination between classes, fewer field samples are generally required for training. This machine learning model is non-parametric and does not require normally-distributed data or independence of attributes. It can also recognize nonlinear patterns in the input data that are too complex for conventional statistical analyses or too subtle to be noticed by an analyst. Feature Analyst software (VLS, 2007) was selected for shoreline extraction from IKONOS imagery, since it employs machine-learning techniques which have the potential to exploit both the spectral and spatial information of the image. It provides a paradigm shift to automated feature extraction since it: (a) utilizes spectral, spatial, temporal, and ancillary information to model the feature extraction process, (b) provides the ability to remove clutter, (c) incorporates advanced machine learning techniques to provide unparalleled levels of accuracy, and (d) provides an exceedingly simple interface for feature extraction. It works by taking a small and simple set of training examples, learns from the examples, and classifies the remainder of the image. When classifying the contents of imagery, there are only a few attributes accessible to human interpreters. For any single set of imagery these are: Shape, Size, Color, Texture, Pattern, Shadow, and Association. Traditional image processing techniques incorporate only color (spectral signature) and perhaps texture or pattern into an involved expert workflow process. The shoreline extraction steps using Feature Analyst are shown in Figure 1.

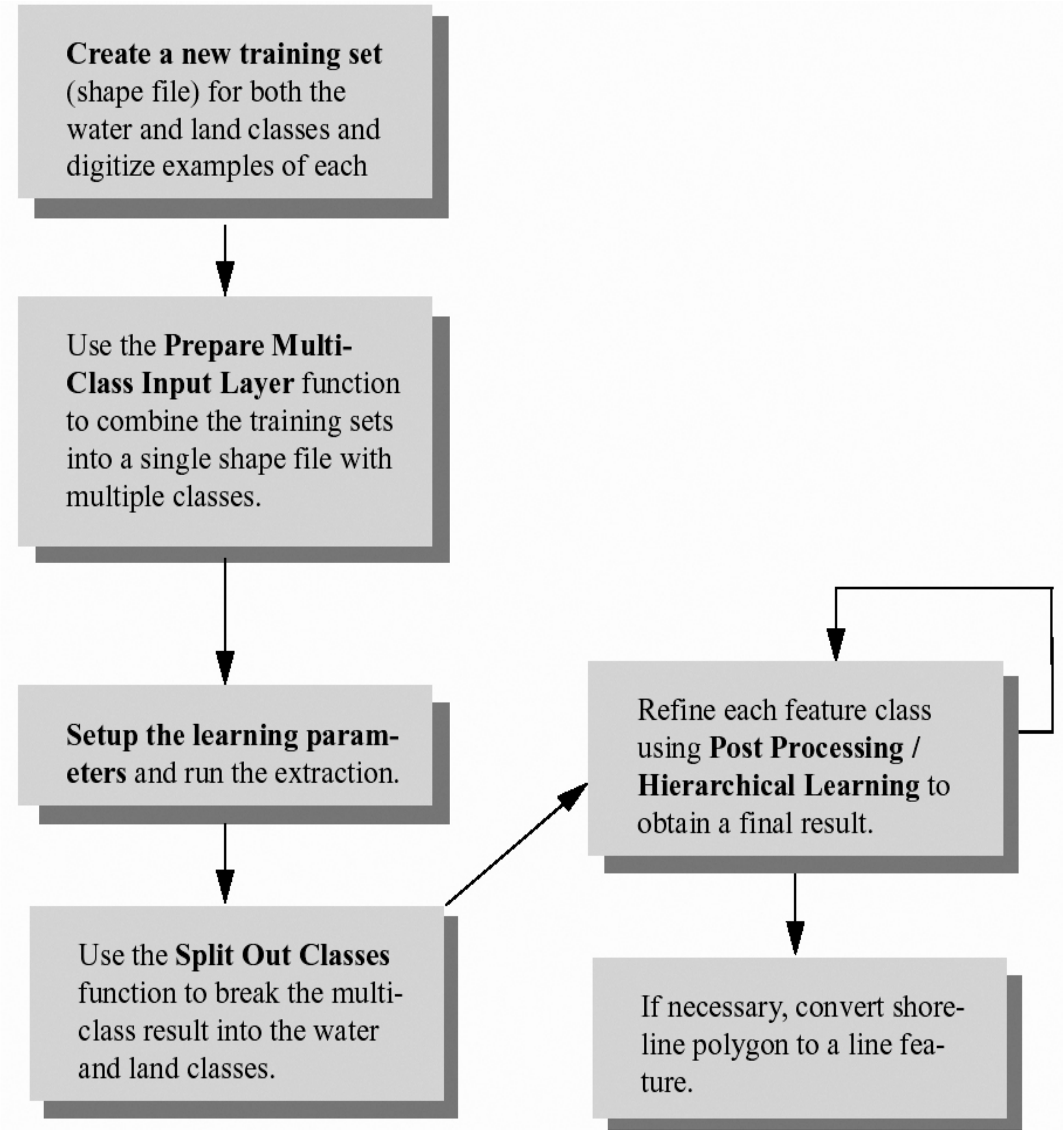

Figure 1. *Shoreline extraction work flow (adapted from VLS, 2007).*

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