IMAGE PROCESSING AND GIS TOOLS FOR FEATURE AND CHANGE EXTRACTION

Costas Armenakis* and Florin Savopol

Natural Resources Canada (NRCan)
Centre for Topographic Information (CTI), Geomatics Canada
615 Booth Str., Ottawa, Ontario, Canada K1A 0E9
{armenaki, fsavopol}@NRCan.gc.ca

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ABSTRACT:

Currently the Centre for Topographic Information, Geomatics Canada, NRCan is involved in issue-based programs, such as the Geomatics for Northern Development and the Reducing Canada's Vulnerability to Climate Change. As in many mapping organizations, the projects within these programs expect the delivery of geospatial data and information in much shorter time periods compared to operations in the past due to the external pressures and the availability of new data sources and technology. This increasing demand for delivery in shorter time imposes a need for rapid approaches for the extraction of topographic features and the detection of landscape changes from imagery. Considering the continuous dwindling of resources, the implementation of higher level of automation in the mapping operations is highly desirable to reduce both the production time and the cost involved, especially when dealing with the vast size of the Canadian territory. To implement rapid processes for mapping operations, such as feature recognition, feature extraction and change detection we have considered the possibilities offered by a) the new kinds of data sources and especially the availability of panchromatic and multispectral digital data; and b) the tools and techniques available in image processing (IP) and GIS packages respectively and how these tools can be used to accelerate the execution of mapping operations. Two case studies, one of which includes the application of CTI's semi-automated change detection approach, are presented to demonstrate the potential, applicability and usefulness of this approach.

1. INTRODUCTION

The Centre for Topographic Information, Geomatics Canada, Natural Resources Canada is involved in issue-driven initiatives, such as the Geomatics for Northern Development Program and the Reducing Canada's Vulnerability to Climate Change Program. Certain projects under these programs conduct acquisition, revision, and monitoring operations for spatial data. Consequently, we require to deal with three main mapping functions: a) the recognition of features, b) the extraction of features, and c) the change detection including correction to existing features. All require extensive human involvement, as they are time consuming operations.

Nowadays, the delivery of geospatial data and information is expected in much shorter time periods compared to the past. This is due to expectations generated by the availability of new technology and new data types and sources. Considering the continuous dwindling resources (human, budgets) and the vast size of the Canadian territory, there is a need to implement rapid mapping approaches to reduce both the production time and the cost involved. These approaches require not only revisiting of the current processes but most important the implementation of higher level of automation in the mapping operations.

Automation for geo-spatial operations, such as feature extraction and change detection has been the "pursue of the holy grail" in photogrammetry, remote sensing and spatial information sciences. While we may never achieve complete automated systems and operations, significant progress has been made for various processes under certain conditions and with specific data types (e.g., Heipke and Straub, 1999; Baltsavias, 2004; Zhang, 2004). This has been leading to some automated operations but mostly to various semi-automated approaches or to tools that can support various semi-automated processes.

An important factor affecting these operations is the high heterogeneity of data and data sources. Data can be vector or raster type, their sources could be geodatabases, raster maps, airborne and/or spaceborne images with various spatial and radiometric resolutions and multi-temporal in nature. Therefore, certain processing is required to normalize the data and bring them under a common work domain, either at the data level or at the information level (Armenakis et al., 2003). In addition, higher levels of automation can be achieved when there is thematic homogeneity and the operations are feature dependent.

In this paper we will identify a range of tools and techniques available in the functionality of geographic information systems (GIS) and the image processing (IP) packages, which can be applied usually in combined modes to accelerate the three main operations of feature recognition, feature extraction and change detection. Two case studies are then presented to demonstrate the applicability of several of these tools in mapping operations.

* Corresponding author

2. IMAGE PROCESSING AND GIS TOOLS IN MAPPING OPERATIONS

There is a significant availability of photogrammetic, image analysis and GIS tools and functionality. The complexity of mapping operations has not yet led to a general approach for the various procedures. However, using the appropriate existing tools it is possible to enhance the operations, to obtain better quality and type of results and to introduce semi-automated approaches. The following sections will present several image analysis/processing and spatial analysis tools and their contributions to the operations of feature recognition, feature extraction and change detection.

2.1 Feature recognition

For the extraction of information from images, the various objects have to be identified through the process of interpretation of the image patterns. The increased availability of multispectral digital data offered by the new sensors allows for "automated" interpretation using spectral pattern recognition and image transform techniques. The simultaneous acquisition of panchromatic and multispectral data allows in addition for implementation of image fusion techniques.

Pixel classification methods allow for the spectral pattern recognition resulting in various thematic categories by classified similar pixels in the same thematic class. The training of the algorithmic classifiers and interpretation of the resulting clusters is done based on human knowledge (e.g., training areas, interpretation of pixel clusters).

In the last few years we have seen the availability of object-oriented image analysis systems, where the basic processing units are image objects and not pixels (eCognition, 2003; Hay et al., 2003; Walter, 2004). The objects are derived through a multi-resolution segmentation based on fuzzy logic classification approaches. The resulted image objects represent the object information from the various image scale levels. The objects in these levels are connected in a hierarchical manner, while each object is also relates to its neighbouring objects. The end result is based on the object class hierarchical inheritance and object aggregation processes.

Another tool for thematic classification is the use of two spectral transformations, which modify the spectral space. The first is the Normalized Density Vegetation Index (NDVI), which is the modulation ratio between the NIR and red bands (Schowengerdt, 1997), and can be used to show vegetation variations or changes appearing in the image. The second is the "Tasseled Cap" (Mather, 1987) spectral band transformation, which is designed for the enhancement of the vegetation cover density and condition. The multispectral bands are used in order to compute three parameters called brightness, greenness and wetness. Brightness is a weighted sum of visible and NIR (VNIR) bands and expresses the total reflection capacity of a surface cover. Small areas dominated by dispersed vegetation appear brighter (high total reflection). Greenness expresses the difference between the total reflectance in the near infrared bands and in the visible bands and has been shown to be moderately well correlating to the density of the vegetation cover. Wetness expresses the difference between the total reflection capacity between the VNIR bands and the short wave infrared (SWIR) bands, and is more sensitive to moisture surface content.

The interpretability of an image can be enhanced through an image fusion (also called sharpening) process (Armenakis, et al., 2003; Forsythe, 2004). Image fusion implies the merging of the higher resolution panchromatic band with the lower resolution multispectral bands. The aim of the fusion is to take advantage of both the higher resolution and multispectral content and to transfer the high frequency content of higher resolution panchromatic image to the lower resolution multispectral image. The result of the fusion is an enhanced multispectral or synthetic imagery of the higher resolution. Various methods for image fusion, such as IHS (Intensity-Hue-Saturation), PCA (Principal Component Analysis), band substitution, arithmetic and Brovey (Pohl and Touron, 2000; Cavayas et al., 2001; Wang et al., 2003), have been applied to enhance the identification of various features.

2.2 Feature extraction

For the primary data acquisition we will address here only the collection of data in mono-mode and we will not address tools and techniques for stereo-mode data extraction. Therefore, we will present only the case of extracting planimetric data from image type data sources, scanned maps included. Usually, the images are orthorectified and the scanned maps are georeferenced.

The extraction of objects from imagery is generally based on two characteristics of the pixel digital number values: a) the similarity and b) the difference of adjacent pixel values. In other words how the discontinuity of pixel grey values is treated and when the abruptions of the intensity values based on certain criteria are significant or not to indicate a boundary between different image features. In addition, the type of feature is considered, that is if we are interested in the extraction of linear or polygonal features. 'A-priori' knowledge or other cues that might exist and can be applied as additional conditions during the feature extraction operations can enhance the extraction procedures.

The property of pixel similarity was discussed also in the section of feature recognition. Therefore the use of pixel classification methods to segment the image regions in thematic polygons is also a tool for extraction of these polygonal features. If their boundaries are required for vector type of data, they can be extracted and then vectorized via an R=>V conversion. The object oriented image classification approach is included in this group.

Thresholding is another extraction method. It is simple and the similarity criterion is based on a range of grey values belonging to the feature of interest, which are used as threshold to separate it from the background image data. It is usually applied on scanned monochrome maps where the map elements are distinguished well from the general background, or on grey images, for example on a NIR Band 5 of Landsat 7 of an area with many water bodies, where the histograms are bi- or multi-modal and can be partitioned by a single or multiple thresholds (Armenakis et al., 2003).

Polygonal image regions can be extracted using their texture description (Haralick, 1979; Zhang, 2001; Kachouie, 2004). Texture represents fineness and coarseness, roughness, contrast, regularity, directionality and periodicity in image patterns. Texture measures can be expressed in terms of variance, mean, entropy, energy and homogeneity of the kernel image window. They can be used to examine the spatial structure of the grey values in an image and analyse the grey level pattern and variations in a pixel's neighbourhood by determining pixels positions that have equal or nearly equal grey values. This grey level variation can be directional or not. While the mean and variance provide a simple description of the statistics of the grey values, the entropy measure provides spatial information of the grey values related to their directionality and frequency of occurrence. Thus it can be used to detect and extract image regions based on the relative degree of randomness of their structure patterns.

When the feature is linear or an edge in an image, edge detection methods can be used to determine sharp changes in the pixel values. These changes in brightness in the two-dimensional image function, $I(x,y)$, are determined by various edge-detection operators based on the two directional partial derivatives, ($\partial I/\partial x$, $\partial I/\partial y$), which are approximated as image pixel differences. Mapping feature operations required selection of specific edges rather than all edges in the image and as much as possible low error in edge detection location and type. The most commonly edge detection operators are the Sobel, Prewitt and the Laplacian. Their disadvantage is that they are sensitive to noise and they might produce more than one response to a single edge. Therefore, one edge operator that is recommended for mapping feature extraction is the Canny operator (Canny, 1986). The Canny operator produces a low error in the detection of an edge, keeps the distance between the detected edge and the true edge to minimum, and has only one response to a single edge (El-Hakim, 1996).

Finally, the quality of feature extraction can be improved with the integration in the process of existing knowledge either as part of the process or as additional constraints. For the former, better knowledge of the type of the training areas will result in high classification accuracies and therefore to higher extraction accuracies. For the latter the idea is based on the principle of determining and establishing conditions that uniquely characterized the features of interest in order to increase the success of recognizing and extracting these particular features from image. These conditions can be applied as "pseudo" bands such as a DEM layer, which can be included in the classification process to improve the classification results for extracting vegetation or buildings (Eiumnoh and Shrestha, 1997; Hodgson et al., 2003). Or they can be applied as spatial constraints, where the extraction of a feature is based on the intersection of conditions-derived spatial layers using logical operators.

Currently most of the efforts for automated or rather semi-automated feature extraction are concentrated on thematic type of extraction, such as roads, water bodies, vegetation, and buildings (Auclair et al., 2001; Jodouin et al., 2003; Baltsavias, 2004; Zhang, 2004).

2.3 Change detection

Change detection requires the comparison of two temporal datasets for the identification and location of differences in their patterns. Although in many cases the comparison must be conducted between heterogeneous datasets, for example "new" image and "old" vector database data, the actual comparison is conducted with homogeneous types of data. That is, the change detection is reduced between image data or between vector data. The former is referred as image-to-image change detection, while the later as feature-based change detection.

2.3.1 Image-to-image. In the case of multi-temporal images we can distinguish two basic approaches. An indirect image change detection, where the change analysis follows an image classification process. The comparison can be done by either differencing the two raster classified thematic layers or by extracting the boundaries of the thematic regions and conduct a vector (i.e., feature-based) change analysis. With this approach we overcome problems related to image acquisition conditions, such as different sensors, atmospheric and illumination conditions and viewing geometries. The accuracy of the detected changes is proportional to the accuracy of the image orthorectification and of the classification results.

The second approach is the direct comparison of two temporal images (Singh, 1989). Various techniques supported by the functionality of IP and GIS systems are:

- image differencing, where the two co-registered temporal images are subtracted pixel-by-pixel. This approach is affected by the various image acquisition conditions and some form of radiometric normalization is applied to both images to reduce these effects. Still the determination of the threshold between change and no-change in the histogram of the difference image is a critical issue for the resulting changes.

- image ratioing, where the ratio of the values of corresponding pixels between the two temporal images are computed. If there is no or minimal change the ratio is close to 1. Again some form of radiometric normalization between the two images needs to be applied, while the selection of the threshold is critical as well.

- image regression, where the pixel values of the second image are assumed to be a linear functions of the corresponding pixel values of the first image. A least squares regression can be used to determine the linear function. Using this function the estimated pixel values for the second image can be computed. The difference image is determined between the estimated second image and the first image using either image differencing or image ratioing. If there is no change the pixel values of the unchanged areas will be close to the estimated pixel values, otherwise there will be changes.

- principal component analysis (PCA) for multispectral multitemporal images, which can be applied either to each of the images and the principal component of each data can be compared with one of the above methods, or can be applied to a combined image consisting of the combined bands of the images to be compared.

2.3.2 Feature-based. For the feature-based approach various functions of spatial analysis are used, such as layer union, layer intersection, buffer generation, and topological overlay. The spatial change $\Delta S_{1,2}$ is defined as the difference between the spatial union of the two temporal homogeneous vector datasets S_1 and S_2 minus their common spatial elements (Armenakis et al., 2003):

$$\begin{aligned}\Delta S_{1,2} &= (S_1 \cup S_2) - (S_1 \cap S_2) \\ &= (S_1 - (S_1 \cap S_2)) \cup (S_2 - (S_1 \cap S_2)) \\ &= D_{el} \cup A_{dd}\end{aligned}$$

This definition allows for the explicit determination of the change components, that is, the additions A_{dd} and deletions D_{el}:

$$A_{dd} = S_2 - (S_1 \cap S_2)$$
$$D_{el} = S_1 - (S_1 \cap S_2)$$

Therefore, an addition is determined as the difference between the new dataset and the common elements between the two temporal datasets, while a deletion is determined as the difference between the old dataset and the common elements between the two temporal datasets. The common elements of the two datasets are determined as the spatial intersection set of the two temporal datasets.

A detected spatial change could be caused by differences in positional accuracies between the two datasets. The significance of change can be expressed based on accuracy tolerances and minimum sizes. To account for positional inaccuracies, appropriate spatial buffers are generated around the two temporal features during the change detection operation, while the minimum sizes satisfying the specifications are handled using appropriate spatial filters. The buffering and filtering operations are used to keep only the actual changes. Whatever vector segments are outside the buffer zones are considered as changes. If the new features from the S_2 data are outside the buffer applied to S_1 features, changes are considered as the actual additions. If the old features from the S_1 data are outside the buffer of the S_2 features, changes are considered as the actual deletions.

3. CASE STUDY I: WATER BODY AREA EXTRACTION FROM LANDSAT 7 IN NORTHERN CANADA

The Landsat 7 ETM+ ortho-images of 15m and 30m spatial resolutions constitute the image layer of the Canadian national data framework. Under the Geomatics for Northern Development Program of the Earth Sciences Sector (ESS) of NRCan, particular attention has been given to the mapping of Northern Canada both for the completion of the 1:50 000 scale coverage and for the updating of existing decades-old data.

Water body areas, such as lakes and rivers are the most predominant features in this northern region of the country. The plethora of water bodies covering the northern areas necessitates the need for rapid approaches for their recognition and extraction. A common approach to automatically extract water bodies is by using land cover supervised or unsupervised classification. However, the existence of other features with similar reflectance, such as glaciers, ice caps, wetlands and shadowing from the mountainous terrain leads to low separability of the thematic classes and increases the confusion level of the results. This results in low accuracy classification and low reliability requiring afterwards significant amounts of interactive editing.

A semi-automated approach for the extraction of water features from Landsat 7 ETM+ imagery has been applied based on image processing and GIS tools combined with a spatial constraint. The approach is based on the principle of determining and establishing conditions that uniquely characterized the water bodies in order to increase the success of recognizing and extracting these particular features from the Landsat 7 ETM+ imagery. The conditions established are based on: a) the spectral properties (digital numbers) of the water bodies as they recorded in the various bands, b) the notion that water bodies are located in areas with zero or minimum terrain slope, and c) the intersection of conditions-derived spatial layers using the AND Boolean operator.

Figure 1: Thresholding on Landsat 7 band 5.

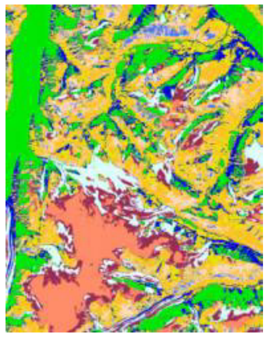

Figure 2: ISODATA clustering using Landsat 7 bands 4,5,7.

Figure 3: Spatial intersection of thresholding output and water class from ISODATA.

Figure 4: Terrain constraint (slope between 0-4 degrees).

Figure 5: Extracted water bodies.

Figure 6: Commission and omission error areas (shown in orange).

The water bodies recognition and extraction approach is based on the application of threshold, spectral, spatial and Boolean operators. First the image was edge sharpened. A thresholding operation was applied on the band 5 based on initial reading of the digital numbers of sample of water bodies and the band histogram followed by a median filter for noise reduction (Fig

1). An ISODATA unsupervised classification was applied using bands 4,5,7. The class related to water bodies was extracted (Fig. 2, in green) and was intersected with the thresholding output via an AND Bolean operator to determine the common areas between this two water related areas (Fig. 3).

An area filter then applied to eliminate water body polygons smaller than the minimum area size. Following, the slope angles were computed from the available DEM and the slope range 0-4 degrees was extracted (Fig 4) and used as spatial constrain, considering that the water bodies are located within this range of slopes. Finally the common areas between the extracted water bodies and the selected slopes were estimated to determine the final areas of water bodies (Fig 5). The commission errors (extraction water body areas where there are not) and omission errors (omission existing water body areas) for the water bodies areas are shown in Figure 6.

4. CASE STUDY II: COASTLINE CHANGE DETECTION

Monitoring of coastal changes contributes to the development of various types of assessments (e.g., impacts, sensitivity, vulnerability, erosion hazard) due to climate change including changes in the sea-level. One of the projects of the ESS Program Reducing Canada's Vulnerability to Climate Change investigates the ocean vulnerabilities to climate change on a regional and local scales to provide critical geoscience data to other government departments. This information can be used in assessing climate change impacts and developing adaptation options. The task of this coastal activity is to develop sensitivity and impacts assessments in coastal areas of the Arctic and East coasts of Canada by using earth observation data to provide the necessary spatio-temporal data infrastructure for coastal areas and by developing methodologies for feature extraction and change detection using image data. The study area is the Arctic south-west coast of Banks Island where the settlement of Sachs Harbour is also located. The time-series data used were 1961 aerial photography and 2002 IKONOS imagery.

The Canny edge detector was used on the 1961 orthophoto to semi-automated extract the coastline (Fig. 7), while due to systems limitations heads-up digitization was used to extract the coastline from the 2002 IKONOS imagery.

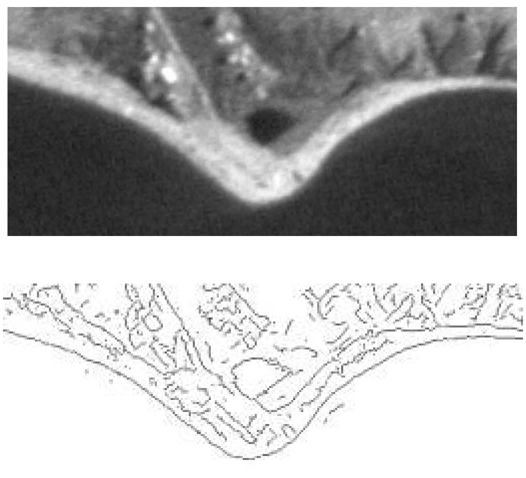

Figure 7: Extraction of coastline using the Canny edge detector.

The extracted pixel edges were converted to vector lines via R=>V process using snapping, smoothing and pseudo nodes removal operations.

For the estimation of the planimetric change detection of the coastline the above described semi-automated feature-based approach, developed at CTI and implemented in the ArcGIS environment, was used. The changes were determined as additions (gains) or deletions (loss) to the land (Fig. 8).

Preliminary results for approximately 39 km length of coast-line show that sea has gained about 446 310 m^2 and land has gained about 351 994 m^2, thus resulting in total loss of land of about 93 316 m^2 between 1961-2002.

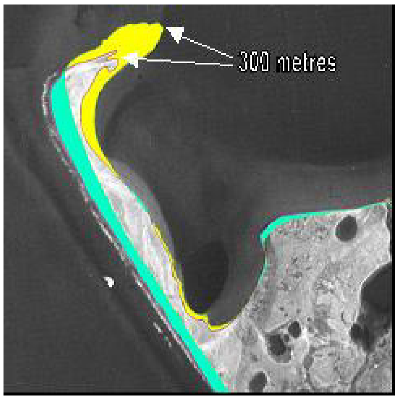

Figure 8: Feature-based coastline change detection between 1961-2002 (land gains in yellow; land losses in light green).

5. CONCLUDING REMARKS

There is a variety of systems and tools available and the trend to integrate photogrammetric, image analysis and GIS functionalities continues. There are new kinds of data sources, such as high resolution images, simultaneous availability of panchromatic and multispectral images, and LIDAR data. And there are new kinds of requirements and applications that required rapid and enhanced mapping operations.

The implementation of higher level of automation in the mapping operations is highly desirable to reduce both the production time and the cost involved, especially when dealing with the vast size of the Canadian territory and the continuous dwindling of resources. To implement rapid processes for mapping operations, such as feature recognition, feature extraction and change detection we have considered several tools and techniques from existing image processing and GIS packages which may be used to either enhance the operations or as alternatives approaches to the procedures. The integrated use of these tools allows also for the development of techniques, such as the presented feature-based change detection, which significantly improves certain operations and results.

However, there is no general solution for the various operations and presently different tools can be used for different data types and occasions. That is, the tools are selected based on the data source and the required outputs, while the accuracy, reliability and completeness of the results may vary from one application to another. This non-standardization of approaches requires specialised personnel and continuous training.

Following the presentation of the various tools and their contribution to the various phases and stages of the main mapping operations of feature identification, feature extraction and change detection, two case studies were presented, where several image processing and spatial analysis tools and techniques have been utilized. These examples demonstrated the potential, applicability, usefulness and viability of this concept towards the implementation of semi-automated approaches for rapid and improved mapping operations and results.

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