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A comparative analysis of scanned maps and imagery for mapping applications

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Abstract

In mapping organizations, the implementation of more automation coupled with the availability of heterogeneous data requires the investigation, adaptation and evaluation of new approaches and techniques. The demand for rapid mapping operations such as database generation and updating is continuously increasing. Due to the rising use of raster data, image analysis techniques have been investigated and tested in this study to introduce automation in the assessment of scanned topographic monochrome maps and Landsat 7 ETM+ imagery for feature separation and extraction in northern Canada. The work focuses on the detection and extraction of lakes—predominant features in the North—as well as on to their spatio-temporal comparison. Various approaches using digital image processing techniques were implemented and evaluated. Thresholding and texture measures were used to evaluate the potential of rapid extraction of certain topographic elements from scanned monochrome maps of northern Canada. A raster to vector approach (R → V) followed for the vectorization of these extracted features. The extraction of features from Landsat 7 ETM+ imagery involved image and theme enhancement by applying various image fusion and spectral transformations (e.g., Brovey, PCI-IMGFUSE, intensity–hue–saturation (IHS), principal component analysis (PCA), Tasseled Cap, Normalized Difference Vegetation Index (NDVI)), followed by image classification and thresholding. Tests showed that the approaches were more or less feature-dependent, while, at the same time, they can augment and significantly enhance the conventional topographic mapping methods. Following the analysis of the map and image data, change detection between two lake datasets was performed both interactively and in an automated mode based on the non-intersection of old and new features. The various approaches and methodology developed and implemented within a GIS environment along with examples, results and limitations are presented and discussed.

Keywords: scanned maps; Landsat 7 ETM+; image analysis; thresholding; texture; entropy; classification; change detection

1. Introduction

Current mapping applications, such as database generation and updating, require the implementation of rapid and economic processes due to the limitations in the available resources. Canada is no exemption to this, especially due to its vast territory, where complete digital coverage from the 1:250 000 topographic data exist for the entire country, while the digital coverage at 1:50 000 scale does not cover the northern parts of the country. Therefore, for certain areas of northern Canada, data at the 1:50 000 scale only exist

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in the form of monochrome paper maps. A program is underway to generate digital topographic data for northern Canada that includes the updating of the existing data. While the digital data generation is possible by scanning and vectorization of the existing reproduction material of the cartographic layers, the associated cost is a major constraint. In addition, using aerial imagery for the updating has its own financial limitations. As the Landsat 7 ETM+ imagery will be the orthoimage layer for the Canadian geospatial infrastructure at the national level, it was decided in this context to initially determine areas and type of changes using this imagery for change detection by comparing the imagery with the scanned topographic monochrome maps. This information can be used then for planning the phases of the database generation and updating for the region.

When comparing two datasets, the domain of comparison has to be defined. For example, vector data provide a classified abstract representation of the landscape, while imagery is an unclassified continuous but resolution-dependent generalized representation of the landscape. If comparing data of the same nature (i.e., two homogeneous satellite images), the change detection can be determined at the *data level* domain (comparison of pre-processed data), while, when comparing heterogeneous datasets, the change detection is performed at the *information level* domain (comparison of analyzed data), as some data processing (e.g., image classification, recognition and separation of feature classes) needs to be done prior to change detection. The latter level is the one used in this study for the analysis and comparison of the scanned topographic map data and Landsat 7 ETM+ orthoimage data due to their heterogeneity. The analysis involves the decomposition of these raster data to basic feature elements (linear or polygonal) using several image extraction techniques based on the various topographic themes.

The extraction process from scanned topographic maps involves the distinction of certain map features belonging to one theme (e.g., water bodies) from other map features and from the map background, followed by the extraction of the exact geometric shape of the feature. Automatic extraction of features from scanned topographic maps has been studied as a viable alternative to manual digitization and for reducing manual editing from raster to vector operations (Carosio and Stengele, 1993; Nebiker and Carosio, 1995). In our study, the separation and extraction process of features from the scanned map were based on similarity of pixel values and on patterns of pixels within a region using image analysis techniques, such as thresholding and texture measures. Then these features are separated from the background via R → V vectorization.

For the Landsat 7 ETM+ imagery, the main concerns were its resolution and the time of the year acquired. To enhance certain features in the imagery, various image transformation techniques were applied, including various fusion approaches of the panchromatic and multispectral bands and the Tasseled Cap and Normalized Difference Vegetation Index (NDVI) spectral transformations. Extraction of features, based on image classification and thresholding, is performed by a R → V vectorization of the boundaries of the identified regions.

2. Analysis of scanned maps

The monochrome (gray scale) topographic maps are scanned at 600 dpi, and then georeferenced and resampled at 2 m. The most common features depicted in these maps are water bodies, rivers, wetlands, vegetation polygons, eskers, contours, text, symbols and the cartographic grid. Certain linear features are represented by varying line width gray values, solid line, dash line or screen line. Polygonal features such as lakes are represented with a screened pattern filling (Fig. 1). These characteristics were considered in determining the extraction approach of certain features from the rasterized monochrome maps. Automated extraction processes were developed and tested using thresholding and texture analysis of the raster map. Some preliminary testing also was performed using template matching for detecting specific symbols (i.e., Fig. 1C top) and assigning the associated attribute value.

2.1. Thresholding

Considering the raster map as a grayscale image, it is possible to apply the thresholding technique using the map histogram. Thresholding permits the distinction, in a raster format, of relevant topographic information, such as the lakes, rivers, wetlands, wooded

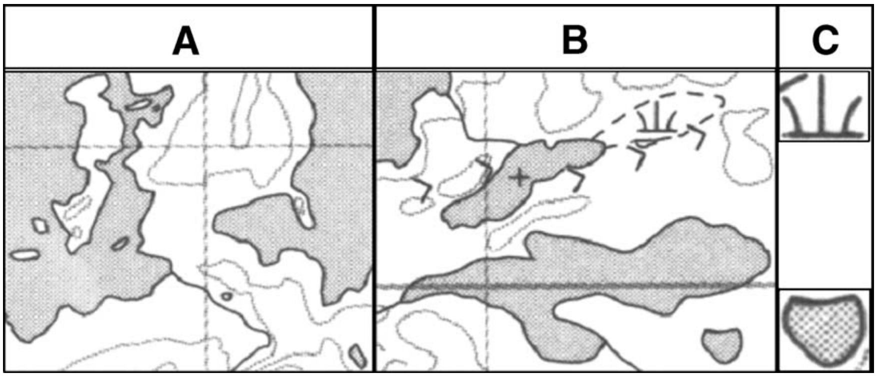

Fig. 1. Appearance of lakes on a 1:50 000 scale monochrome map. (A, B) Two different areas showing lakes (in gray). (C) Some elements of (B) enlarged.

areas, eskers, roads, etc., from contours and grid lines. The map thresholding is defined as following, where certain elements of the map $f_m(x,y)$ are extracted from the monochrome raster map image $r_m(x,y)$ based on a thresholding interval of gray values g_i and g_j:

$$f_m(x,y) = \begin{cases} 1 \text{ for } g_i \le r_m(x,y) \le g_j \\ 0 \text{ for } r_m(x,y) < g_i \text{ and } r_m(x,y) > g_j \end{cases} \tag{1}$$

This method uses the fact that the map lines, which delineate or represent most of the cartographic information (including symbols and toponymy), appear much darker than contours and grid lines. The most appropriate threshold value g_j (considering $g_i = 0$) has to be determined by the operator, since this value may vary according to the printing and scanning specifics. The result of the map thresholding is then filtered using median and sieve filters to remove noise and all polygons that are smaller than a given minimum size, measured in pixels. The level of filtering must be chosen adequately to both keep small or isolated feature map lines and remove enough grid lines and contours that may reduce the feature visibility.

Vector features are obtained for the change detection process through an R → V conversion (interactive or automatic) of thresholded results. Although 'intelligent' approaches exist for recognition and conversion of features from scanned maps to structured GIS elements (i.e., Mayer et al., 1992; Nebiker and Carosio, 1995; Gold, 1997), the vectors of raster elements representing certain features were generated by an automatic direct vectorization process of the thresholded output. Nevertheless, there is a limited use of these output vectors because of the fact that they are not topologically structured and include map elements such as symbols and text. An example of these vectors is presented in Fig. 5.

2.2. Texture analysis

Texture measures have been studied for sometime (Haralick 1979; Haralick and Shapiro, 1992) and are used to examine the spatial structure of the gray values in an image. Texture is an important characteristic for analysis of images. It can be used to define fineness and coarseness, roughness, contrast, regularity, directionality and periodicity in image patterns. Texture can simply be defined as the analysis of gray level pattern and variations in a pixel's neighborhood. This gray level variation can be directional or not. Texture measures can be expressed in terms of variance, mean, entropy, energy and homogeneity of the kernel image window.

Based on these measures and the filling pattern of the water bodies, a method has been implemented to automate the extraction of lakes from the scanned maps. This automated extraction is limited to lakes that appear, in the 1:50 000 scale monochrome maps, in polygonal screened gray pattern, while the rest of the map is represented by linear patterns (see Fig. 1). In this experiment, the following texture measures have been tested for cartographic patterns, such as the screened lake fills: mean, variance and entropy. The

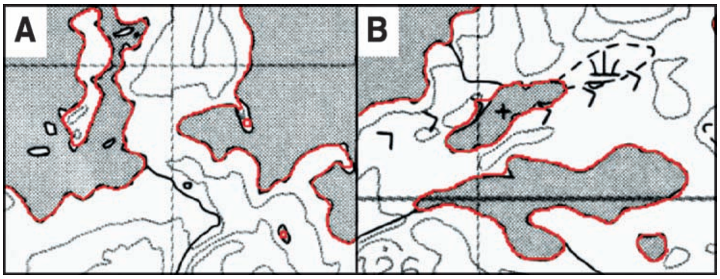

Fig. 2. Examples (continuous red lines) of lake extraction from scanned map using the entropy measure (areas A and B).

mean and variance provide a simple description of the statistics of the gray values, while the entropy provides spatial information of the gray values related to their directionality and frequency of occurrence. As such, preliminary results have shown that the entropy parameter was the most promising. The entropy measure of texture analysis, where the cartographic patterns of certain polygonal elements are extracted based on the relative degree of randomness of their pattern, is defined as:

$$\text{Entropy} = \sum_{a,b} \mathbf{P}_{\gamma,d}(a,b)\log(\mathbf{P}_{\gamma,d}(a,b)) \qquad (2)$$

where **P** is the co-occurrence matrix, describing how frequently two pixels with gray values a, b appear in a kernel window separated by distance d in direction γ (Sonka et al., 1993). In our experiment, we used a distance of 1 pixel between two neighboring pixels and a directional invariant outcome. The degree of detection of small objects depends on the kernel size of co-occurrence matrix of the entropy measure (11×11 pixel kernel was used). A larger size kernel allows for more data to compute a significant entropy measure, but reduces the ability to detect small objects.

The steps to automatically extract the lake boundaries are: (1) apply a texture filter to the raster map; (2) threshold the resulting image between lakes and no lakes; (3) apply a median filter to eliminate noise; (4) filter to remove lakes that do not respect the minimum size requirement; and (5) vectorize the binary image obtained in Step 4. Vectors resulting from this method are shown in Fig. 2.

If we compare results obtained by the texture (Fig. 2) and by the thresholding and filtering (Fig. 3) approaches, the texture-based lake extraction process permits the quick extraction and subsequently vectorization of the general shape of lakes, but it also imposes some limitations in the detection of small islands or lakes, narrow water passages or peninsulas and in the delineation of the shape of the features. Fig. 4 shows the comparison between the automatic vectorization (from texture analysis) and the interactive vectorization for the extraction of lakes. In the case of map thresholding, the result contains more information as rivers, marshes, eskers, etc. and represents more accurately and in more detail the map content. However, the vectorization of the thresholding output requires more

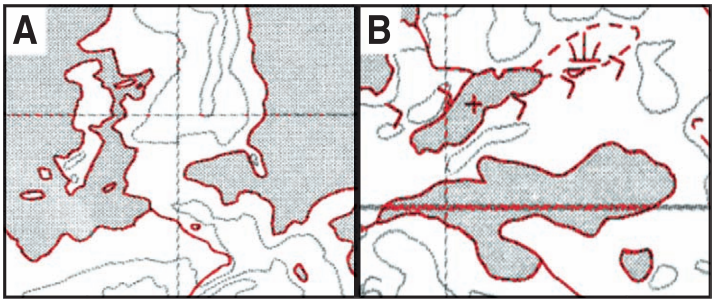

Fig. 3. Examples (continuous red lines) of lake extraction from scanned map using thresholding method (areas A and B).

editing compared to the texture-based lake extraction, as it is unable to extract the lakes only.

3. Analysis of Landsat 7 ETM+ imagery

Landsat 7 ETM+ imagery, by its ground resolution, is limited in its capacity of detection and extraction of 1:50 000 scale map features. Some features, extracted from scanned maps (see Section 2), are not visible or not distinguishable in the image (esker, creek, point features, etc.). Regarding the geographic location, the topography of the terrain and the type and number of topographic features to consider, the time of the year for image acquisition also represents an important limiting factor. To improve the capacity for feature distinction and interpretation from the Landsat 7 ETM+ imagery, various image enhancement techniques (radiometric, spatial and spectral) were applied prior to any feature extraction. Specifically for feature recognition, we have tested various image fusion, Tasseled Cap and NDVI image transformations. Feature extraction was then performed by either image classification or thresholding followed by automatic vectorization.

3.1. Image enhancement

3.1.1. Image fusion

Image fusion of the Landsat ETM+ image data implies the merging of the higher resolution panchromatic band (ETM-8, 15 m) with the lower resolution (30 m) multispectral bands. The aim of the fusion is to take advantage of both the higher resolution and multispectral content. The result of the fusion is an enhanced multispectral or synthetic imagery of the higher resolution. Various methods for image fusion, such as intensity–hue–saturation (IHS), principal component analysis (PCA), band substitution, arithmetic and Brovey (Pohl and Touron, 2000; Cavayas et al., 2001), were tested as to their enhancement potential of various features.

IHS is the transformation of three multispectral channels into intensity–hue–saturation color space. Afterwards, the intensity channel is replaced by the panchromatic band, and the IHS image is converted back into red–green–blue (RGB) color space. The arithmetic method is simply the addition of the panchromatic channel to each multispectral channel. Another way of using this additive method is to enhance the panchromatic band with a high-pass filter. The filtered panchromatic band is then added to each multispectral channel. Finally, the Brovey transform is the multiplication of a multispectral channel, divided by the sum of all multispectral channels used, by the panchromatic band, as follows (Cavayas et al., 2001):

$$\mathbf{B}_i = \left(\frac{\mathbf{MS}_i}{\sum_i \mathbf{MS}_i} \right) \mathbf{P} \tag{3}$$

where $\mathbf{B}_i$ is a fused channel, $\mathbf{MS}_i$ is the i multispectral channel to be fused, $\mathbf{P}$ is the panchromatic band and $\Sigma \mathbf{MS}_i$ is the summation of all multispectral channels (six in our case).

The PCA approach was used for image fusion as well. It decorrelates the data into fewer bands (called principal components) that contain the maximum intensity variance corresponding to main information that could be extracted (redundant data are then reduced). The PCA was applied in this work using seven bands (six multispectral and one panchromatic) and the first three components were selected to represent the fused output image. Another approach would be to apply the PCA on the six multispectral bands followed by an IHS transform of the first three components and replacing the Intensity channel with the panchromatic one.

We also used the IMGFUSE routine of the PCI software package that is based on cross-correlation between high and low resolution bands (computed band by band). The advantage of this fusion method is that it preserves the radiometric properties of the original multispectral channels (Cheng et al., 2000), while IHS and PCA usually distort them (Chavez et al., 1991). Its main inconvenience is that it results in some local blurring depending on the level of correlation.

Comparing the results of various image fusion techniques for Landsat 7 ETM+, no significant difference for feature recognition was noticed between simple and more computationally intensive methods. Edge-sharpening filter (High-Pass Filter)

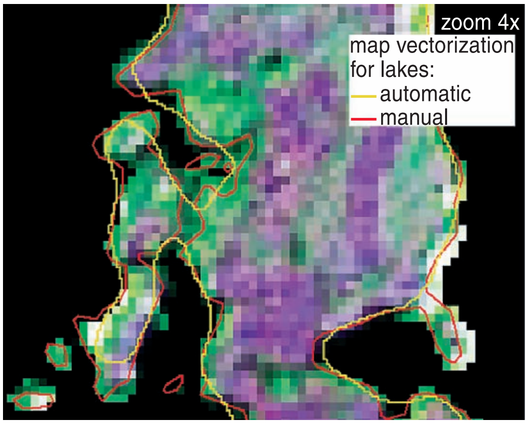

Fig. 4. Extraction of lakes from two methods (vector outputs). Yellow: Lakes extracted automatically (from texture analysis). Red: Lakes extracted interactively.

of the panchromatic band generally improved the fusion results.

3.1.2. Spectral transformations

One of our test areas is located in a northern region of Alberta, Canada (centered on 115°45′W and 57°37′N), in a zone characterized by important vegetation coverage (mixed boreal forest). As the vegetation cover seems to be an important factor in modulating the information content of the various Landsat 7 bands (acquired on May 29, 2000), a spectral band transformation expressly designed for the enhancement of the vegetation cover density and condition, called the "Tasseled Cap" was applied (Mather, 1987). The six multispectral bands of Landsat 7, excluding the thermal band, were used in order to compute three parameters called brightness, greenness and wetness. Brightness is a weighted sum of all six ETM channels 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 visible-near infrared (VNIR) channels and the short-wave infrared (SWIR) channels, and is more sensitive to moisture surface content.

Besides Tasseled Cap transformation, the **NDVI** was also calculated to enhance vegetation variations or changes appearing in the image, where

$$\mathbf{NDVI} = \frac{\mathbf{ETM4} + \mathbf{ETM3}}{\mathbf{ETM4} - \mathbf{ETM3}} \tag{4}$$

and **ETM3** is the red band (0.63–0.69 μm) and **ETM4** is the NIR band (0.76–0.90 μm).

3.2. Feature extraction from the image

Based on the geographic location, the land cover and the time of the year for image acquisition, the choice of feature extraction technique depends on the theme considered.

3.2.1. Classification

Noting that field ground truth and verification are not available, the existing geospatial databases were used as 'prior knowledge' to provide cues and guidance in the classification process. This knowledge is used as contextual information for selecting training sites for pixel-based classification.

For the classification process, we used as input data the three bands of the fused image (PCI-IMGFUSE routine) corresponding to ETM-3, ETM-4 and ETM-5, the three Tasseled Cap parameter channels (brightness, greenness and wetness) and the NDVI channel. The training sites were selected considering our prior knowledge of the topographic features that are scanned map vectors and 1981 fire polygons obtained from the Alberta Sustainable Resource Development, Forest Protection (Fig. 5).

Concerning certain features such as wetlands or wooded areas, the selection of training sites is somewhat difficult due to the variation in spectral signatures for these features. These variations could reflect the presence of sub-classes in the defined topographic feature (e.g., clear cuts, burned areas and regenerated forests are included in wooded areas, while all types and conditions of swamps and marshes are included in wetlands). To take into account these spectral variations even though they are not reflected in the map content, different training sites have to be selected to create several sub-classes for the same feature. After the classification process (by maximum of likelihood), sub-classes were aggregated to adapt the detected classes to

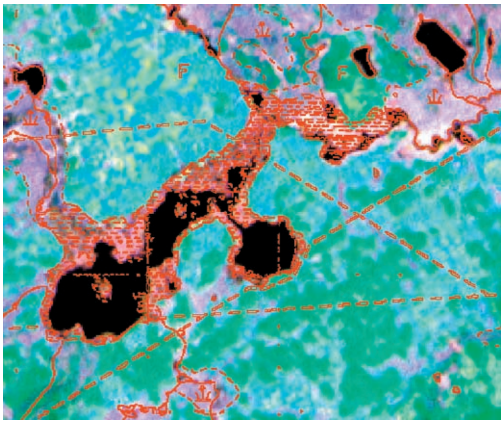

Fig. 5. Fused image ETM-3-4-5 superimposed with map content vectors (in red).

general categories of map elements (vegetation, wetlands and water bodies). In this case, six sub-classes were extracted (water bodies, marshes, swamps, recent cuts, burned areas and wooded areas) and aggregated to obtain three final classes (water bodies, wetlands and vegetation). Based on our training sites, the κ coefficient was 0.95. In comparison, without image fusion, the classification leads to κ coefficient of 0.87. The κ coefficient (or KHAT index) indicates if the classification error is significantly reduced compared to the error of a completely random classifier (Congalton et al., 1983). Thus, the value of 0.95 indicates that the classification performed has avoided 95% of the errors produced by a totally random assignment of land-cover classes to the pixels.

Following the supervised image classification, classes detected and properly identified are extracted and then filtered to consider the minimal size specifications of the map. Then, the boundaries of the classified regions are subsequently vectorized. Tests for feature extraction from imagery using classification have been limited to polygonal features.

3.2.2. Thresholding

A Landsat 7 ETM+ image was acquired on June 14, 2000 covering a taiga zone located in the North West Territories, Canada (centred on 111°15′W and 63°52′N). At this latitude and time of the year, most of the large lakes are still frozen. Within the smaller lakes, most of the covering ice was melted. The difference between frozen and unfrozen lakes with spectral band ETM-1 to ETM-4 was clearly visible. Spectral bands ETM-5 and ETM-7 did not show this distinction. This fact is important, as we are not interested in this difference. Fig. 6A and 6B gives a visual comparison between band ETM-5 and bands ETM-3-4-5 with the overlay of map vectors.

Classifying the water with bands ETM-1 to ETM-4 and even with ETM-8 (panchromatic) was difficult because of the difference between frozen, unfrozen water and even within the ice coverage. Finally, a simple region thresholding of band ETM-5, considering values (gray levels) from 0 to 25, allowed for the extraction of the lakes (Fig. 6C). In all the fusion experiments, few feature improvements were obtained because of the nature of each spectral band, the nature of the land cover and its state, and the time of acquisition of the image (frozen water, wet soils, coarse vegetation, etc.). In this particular case, only lakes could be extracted by a simple thresholding (no fusion and supervised classification were applied).

4. Example: actual change detection

The analysis of the two datasets (scanned map and Landsat 7 ETM+ imagery) permits the detection and extraction of homogeneous topographic features to be compared at the *information level*. The detection of actual changes (where the actual change is defined as the spatial differences minus any errors in the data and the approach) in these homogeneous vector spatial patterns can be performed in an interactive or automated manner. The interactive approach is based on the superimposition of the extracted vector data from either the map or the image with either the image or the map as background. The change is visually detected by the operator and extracted by heads-up digitizing.

In the automated approach using the vector data in a GIS system, the change is defined as the non-intersection of the old and new vector features between two temporal spatial states (S_1 and S_2). The changes consist of additions and deletions. A deletion is the difference between the old state and the common elements between the two states, while an addition is the difference between the new state and the common elements between the two states. If the

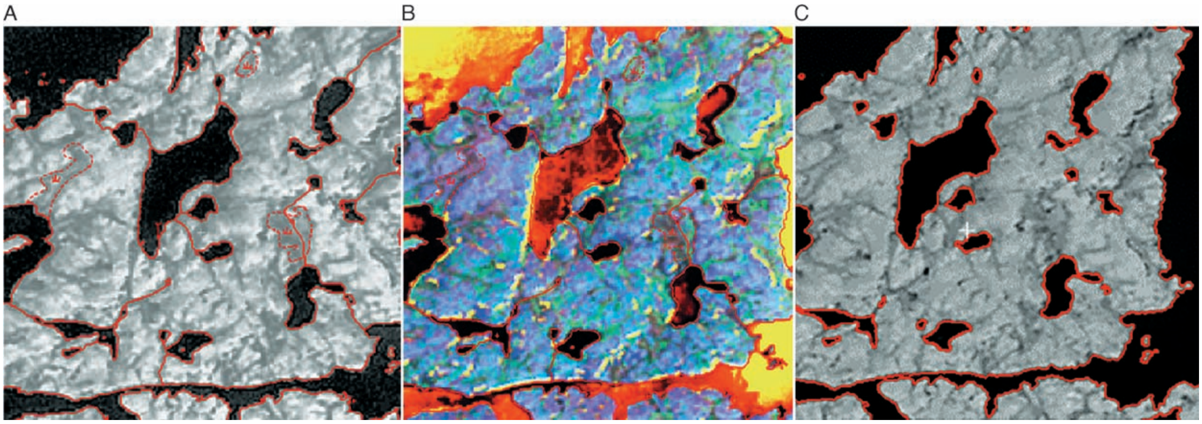

Fig. 6. Band ETM-5 (A) and ETM-3-4-5 (B) with map vectors obtained by thresholding (red). (C) Extraction of lakes from ETM-5 band (vectors in red).

output of the non-intersection contains data from S_1, then changes are considered as deletions. If it contains data from S_2, changes are considered as additions. The total changes and the additions and deletions are then expressed as follows:

$$C = A + D \quad (5)$$

$$A = S_2 - S_1 \cap S_2 \quad (6)$$

$$D = S_1 - S_1 \cap S_2 \quad (7)$$

where C = total spatial change, A = additions, D = deletions, S_1 = spatial state at time 1 and S_2 = spatial state at time 2.

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 accuracy tolerances, appropriate spatial buffers are generated around both features during the change detection operation, while the minimum sizes

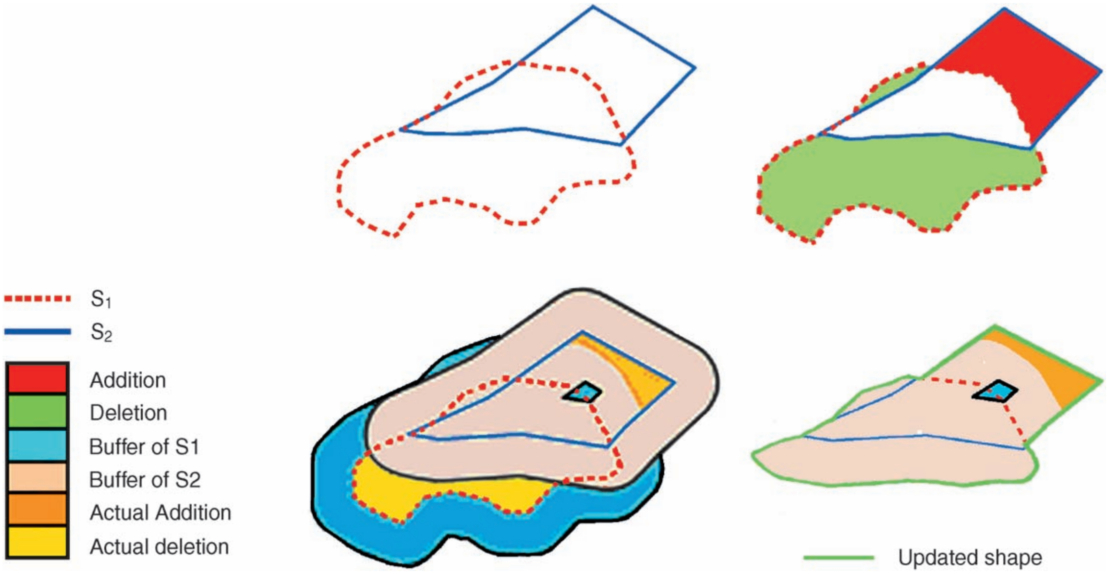

Fig. 7. Addition, deletion and actual spatial change detection.

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: (a) 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; and (b) 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 (Fig. 7). This approach has been implemented in the ArcGIS environment to allow for the automated detection of spatial changes as well as for the quantification of changes per theme by calculating, for example, total length and/or area of change.

Fig. 8 presents the steps for this automated change detection implementation between old lake map vectors and new lake vectors extracted from band ETM-8 of Landsat 7. The non-intersection method is applied directly on the original vectors (Fig. 8A) to obtain

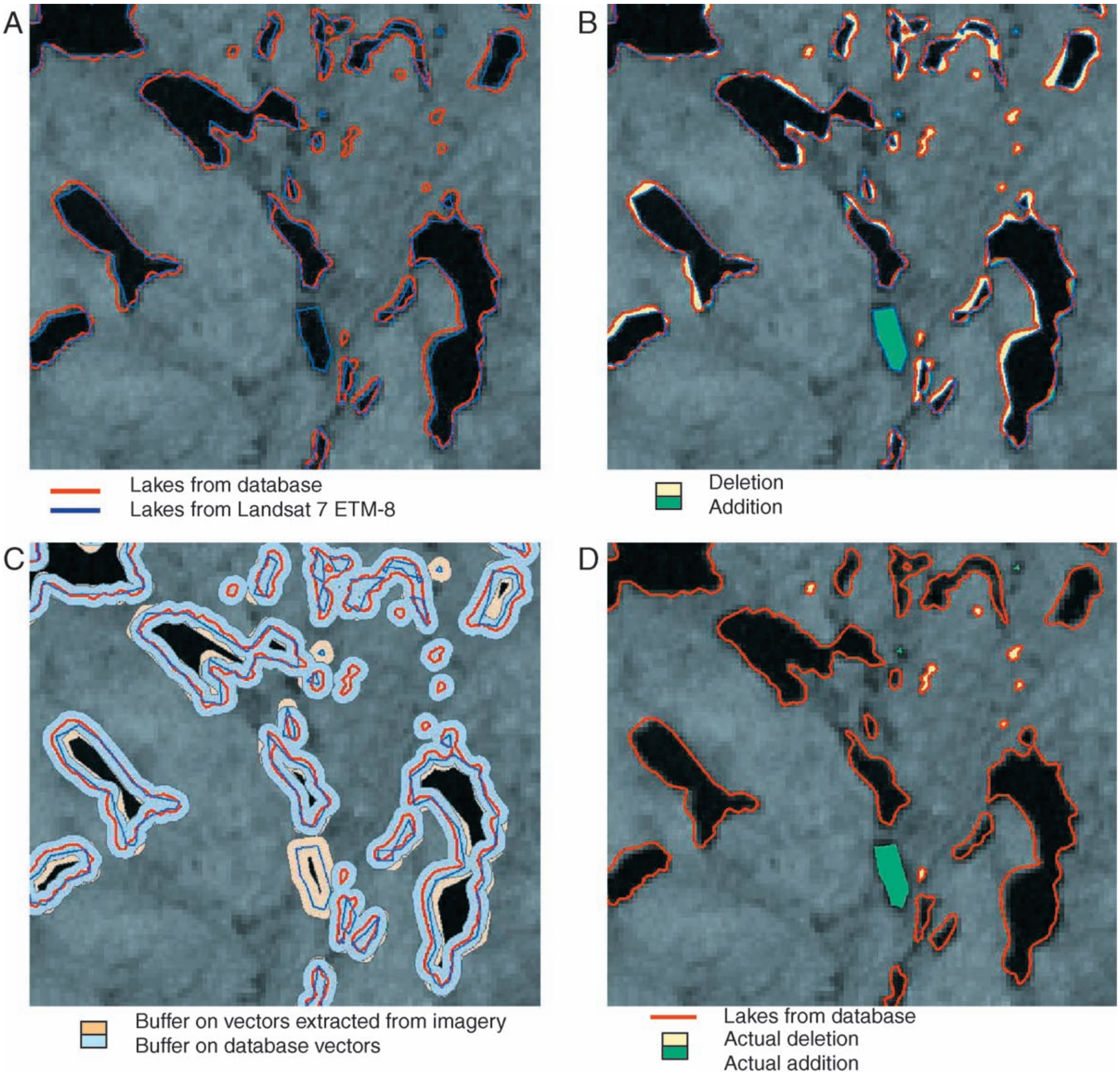

Fig. 8. Change detection between old and new lake vectors.

addition and deletion zones representing the change (Fig. 8B). Then a 30-m buffer is generated around both original vectors to consider the planimetric accuracy tolerance (Fig. 8C). The non-intersection method between the deletions and the new-buffered vectors determine the actual deletions, while the non-intersection method between the additions and the old buffered vectors determine the actual additions (Fig. 8D).

5. Conclusions

The demand for rapid mapping operations such as database generation and updating is continuously increasing for mapping organizations. The requirement for implementing more automation coupled with the availability of heterogeneous data is pushing towards the adaptation of new approaches and techniques. Due to the increased use of raster data, image-processing techniques have been investigated and tested in this study to introduce automation in the process of detection and extraction of certain topographic features. These alternative approaches to conventional topographic methods were investigated and tested for a comparative analysis of scanned maps and satellite imagery. The extracted topographic features were used for the change detection requirements.

In our study, the separation and extraction process of features from the scanned monochrome maps of northern Canada were based on similarity of pixel values and on patterns of pixels within a region using image analysis techniques such as thresholding and texture measures. These features are then separated from the background via R → V vectorization. Fully automated vectorization of the raster map requires the development and implementation of pattern recognition techniques for symbol identification and extraction of various cartographically represented elements based on 'intelligent' models, which presently are distinguished with human intervention. Concerning the imagery, besides the limitations posed by the resolution and the acquisition time of the Landsat 7 ETM+ imagery, image and theme enhancements were performed by applying various image fusion (e.g., IHS, Brovey, PCA and PCI-IMGFUSE) and spectral enhancement (e.g., Tasseled Cap and NDVI) transformations. Image thresholding and image classification were applied for the extraction of areal features from the imagery. The tests showed that the feature extraction operations in particular were more or less feature-dependent.

The data sets to be compared at two or more time periods could vary in nature and homogeneity. In our case, the initial data set was monochrome raster maps, while the new data set was Landsat 7 ETM+ image. As the two data sets were not originally homogeneous, the comparison for the detection of planimetric changes was performed on vectorized data extracted from both data sets. Having defined and pre-processed the data sets for the epoch comparison, the actual change detection was performed both interactively and automatically based on the non-intersection of old and new features. The tests showed that interactive change detection approaches can be improved when enhanced data sets are used, while the incorporation of image processing techniques supports the efforts to automate the production operations. The applicability of the proposed automated process—tested on lake features in our cases—for the determination of differences between two homogeneous vector datasets can be extended to other vector features as well. Research work needs to continue to provide new improved approaches and tools for rapid and flexible analysis of scanned maps and multi-temporal image, including the change detection and updating operations using multi-temporal imagery. These efforts will support the generation of structured spatial data for the maintenance and updating of geospatial databases.

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References

Carosio, A., Stengele, R., 1993. Automatic pattern recognition for economic map revision. Proceedings of the 16th International Cartographic Conference, Cologne, Germany, vol. 1, pp. 518–526.

Cavayas, F., Gonthier, E., Leduc, F., 2001. Planimetric features enhancement of Landsat 7 satellite imagery using fusion techniques. Contract final report submitted to Centre for Topographic Information, Geomatics Canada, 77 pp.

Chavez, P.S., Sides, S.C., Anderson, J.A., 1991. Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic. Photogrammetric Engineering and Remote Sensing 57 (3), 295–303.

Cheng, P., Toutin, T., Tom, V., 2000. Orthorectification and data fusion of Landsat 7 data. Proc. Annual ASPRS Convention, Washington, DC, May 22–26 (on CD-ROM).

Congalton, R.G., Oderwald, R.G., Mead, R.A., 1983. Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques. Photogrammetric Engineering and Remote Sensing 49 (12), 1671–1678.

Gold, C.M., 1997. Simple topology generation from scanned maps. Proc. ACSM/ASPRS-Auto Carto 13 Conference, Seattle, WA, vol. 5, pp. 337–346.

Haralick, R.M., 1979. Statistical and structural approaches to texture. Proceedings of IEEE 67 (5), 786–803.

Haralick, R.M., Shapiro, L.G., 1992. Computer and Robot Vision, vol. 1. Addison-Wesley Publishing, Reading, MA.

Mather, P.M., 1987. Computer Processing of Remotely-Sensed Images. Biddles, Guildford, Surrey, Great Britain. 352 pp.

Mayer, H., Heipke, C., Maderlechner, G., 1992. Knowledge-based interpretation of scanned large-scale maps using multi-level modeling. International Archives of Photogrammetry and Remote Sensing 29 (B3), 578–585.

Nebiker, S., Carosio, A., 1995. Automatic extraction and structuring of objects from scanned topographic maps—an alternative to the extraction from aerial and space images? In: Gruen, A., Kuebler, O., Agouris, P. (Eds.), Automatic Extraction of Man-Made Objects from Aerial and Space Images. Birkhauser Verlag, Basel, pp. 287–296.

Pohl, C., Touron, H., 2000. Issues and challenges of operational applications using multisensor image fusion. In: Ranchin, T., Wald, L. (Eds.), Proc. Fusion of Earth Data. Sophia Antipolis, France, pp. 25–31.

Sonka, M., Hlavac, V., Boyle, R., 1993. Image Processing, Analysis and Machine Vision. Chapman and Hall, London, Great Britain. 555 pp.