Registration-noise reduction in difference images for change detection

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Abstract. Two methods are introduced and evaluated for the reduction of registration noise in difference images: image smoothing and adaptive grey-scale mapping. Landsat Thematic Mapper (TM) data obtained on two different dates over an urban and urban-fringe area depicting significant change were geometrically registered and then subtracted from each other. The TM band 3 difference image was used to test the registration noise reduction algorithms. Results indicate that adaptive grey scale mapping is more appropriate to use for registration noise reduction.

1. Introduction

A difference image for change detection is obtained by spatially registering two images acquired at different times and then subtracting one image from the other on a pixel-by-pixel basis. This requires the use of geometric-correction algorithms that register the images to each other or to a map projection (Jensen 1981). In change detection, the optimum situation is when illumination and atmoshere differences between the two images are minimal and they are registered as close to each other as possible. However, none of these conditions can be achieved easily.

If two images are not in perfect alignment before subtraction, their difference image will contain artefacts caused by incomplete cancellation of the unchanged background objects. These artefacts are referred to as 'registration noise'. It has been suggested that geometric correction should result in the two images being within half a pixel of each other (Jensen 1981). If this accuracy can be achieved, the registration noise is likely to be less intense than the difference of any real change and commonly used thresholding algorithm may be sufficient to redeuce such noise. However, it is often difficult to keep the geometric correction error below half a pixel for the entire image. The so-called 'standard error' or 'average residual error' provided by existing geometric-correction software are only estimates from many individual pixels (ground control points) selected from both images. This type of error index inevitably underestimates the actual registration noise in difference images.

In this Letter, two methods for registration-noise reduction are evaluated for remote sensing change detection using difference images. The first method uses a smoothing filter and the second uses a technique called adaptive grey-scale mapping proposed by Knoll and Delp (1986). These methods were applied to Landsat Thematic Mapper (TM) data acquired over an urban area and its fringe. Some preliminary results are presented.

2. Methods

Image smoothing can be used in registration-noise reduction. This is done by moving an average filter or a median filter over the difference image and replacing the centre pixel of the corresponding pixel neighbourhood with the averaged result of the median grey level. While suppressing registration noise, the smoothing method removes real change from a difference image.

Knoll and Delp (1986) proposed an adaptive grey-scale mapping method. It has been used successfully in detecting changes from laboratory pictures of a computer terminal. It takes three steps for this method to reduce registration noise: a Sobel edge filter is applied to each original image to enhance object boundaries; Edge-enhanced images are then subtracted to generate a difference image; Finally, the adaptive grey-scale mapping algorithm is used to the difference image.

For change detection by remote sensing, an edge filter has two drawbacks: it removes spectral differences between spatially homogeneous areas, and it adds noise to each image. The effects of spectral-difference removal will make it impossible to detect spectral changes that have occurred in spatially homogeneous areas such as those which show seasonal changes of crops. The increased noise will be accumulated in the difference image, which is then difficult to remove. Therefore, only the third step of the Knoll and Delp approach, the adaptive grey-scale mapping algorithm, is used in this study.

A simple version of the algorithm can be illustrated using a one-dimensional signal containing an unchanged bright target and its background during time periods $T1$ and $T2$ (figure 1). If the registration is perfect, the bright target will be cancelled out on the difference image (figure 1(*a*)). Otherwise, a bright and a dark signal may appear on the difference image (figure 1(*b*)). For this situation, the adaptive grey-scale mapping will 'cut' the bright signal and 'fill' it into the dark one (figure 1(*c*)).

Mathematically, this is performed on the difference image by calculating the total excess and deficit of grey-level value with respect to the image mean in a pixel

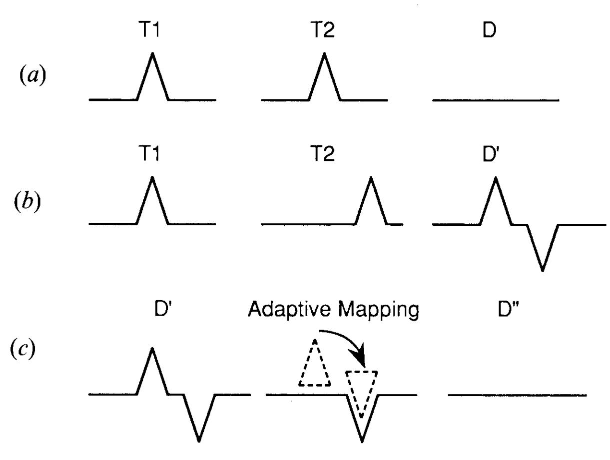


Figure 1. Registration-noise reduction through adaptive grey-scale mapping: (*a*) a difference signal (D) obtained when there is no registration noise between times $T1$ and $T2$; (*b*) a difference signal (D') when registration noise exists; and (*c*) a difference signal (D'') corrected from D' using adaptive grey-scale mapping.

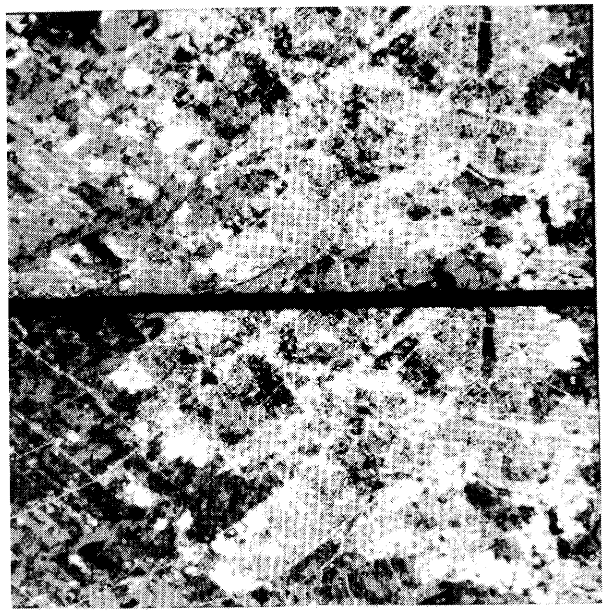


Figure 2. A black-and-white image of the standard colour composite of TM bands 2, 3 and 4, with the 1985 scene shown on the top and the 1986 scene shown at the bottom.

window with a lateral window size of $2w+1$. First, a difference, $\Delta(i,j)$, is obtained between any pixel value $D'(i,j)$ and the mean or median, m, of the difference image:

$$\Delta(i,j)=D'(i,j)-m$$

For each pixel window, the amount of brightness, $b(i,j)$, and darkness, $d(i,j)$, is obtained by

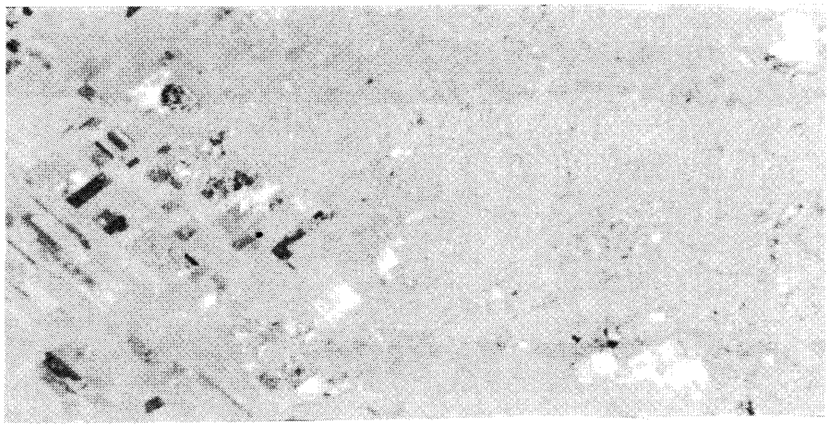
$$b(i,j)=\sum_{k=i-w}^{i+w}\sum_{l=j-w}^{j+w}\Delta(k,l) \qquad \text{if } \Delta(k,l)>0$$

$$d(i,j)=\sum_{k=i-w}^{i+w}\sum_{l=j-w}^{j+w}\Delta(k,l) \qquad \text{if } \Delta(k,l)<0$$

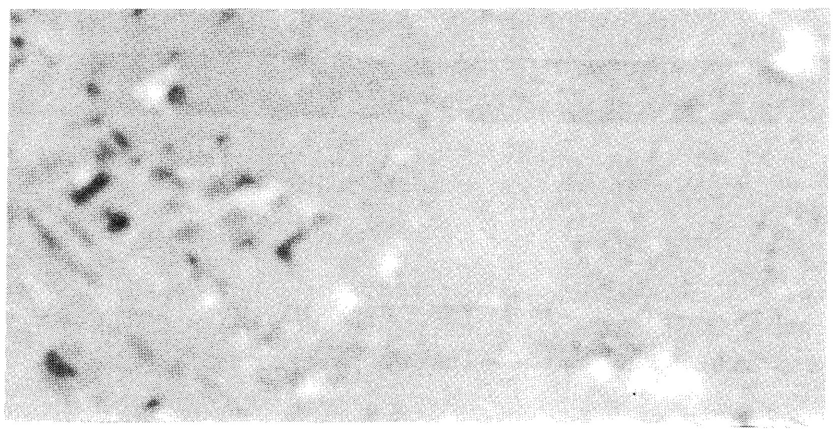
Since there is no effective way to determine the optimum pixel window size, this size has to be determined empirically. The adapted grey level of each pixel, $D''(i,j)$, is obtained through

$$D''(i,j)=\begin{cases} m+\Delta(i,j)\times(b(i,j)-d(i,j))/b(i,j) \\ \qquad \text{if } \Delta(i,j)>0 \text{ and } b(i,j)>d(i,j) \\ m-\Delta(i,j)\times(b(i,j)-d(i,j))/b(i,j) \\ \qquad \text{if } \Delta(i,j)<0 \text{ and } b(i,j)<d(i,j) \\ m \text{ otherwise} \end{cases}$$

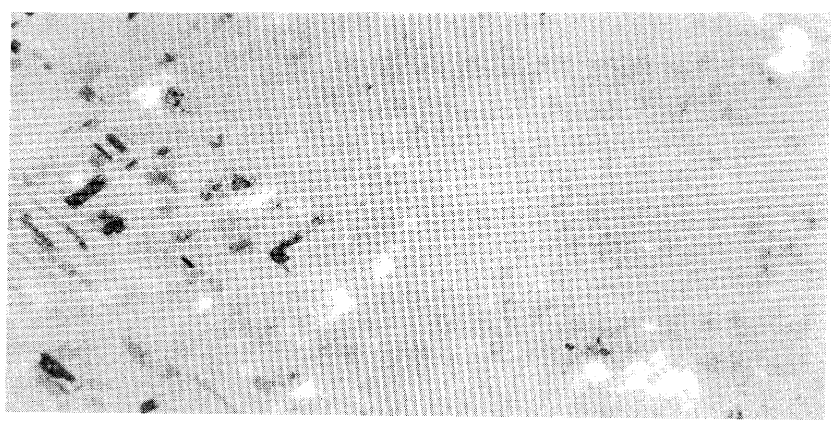
A detailed description of the adaptive grey-scale mapping method can be found in Knoll and Delp (1986).



(*a*)

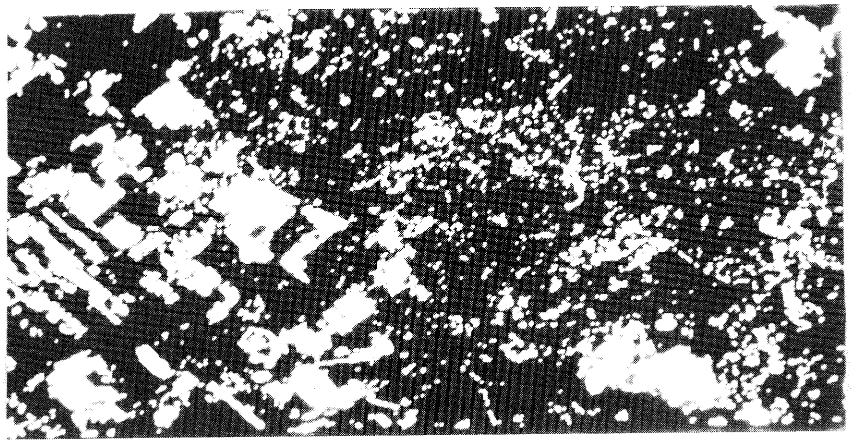


(*b*)

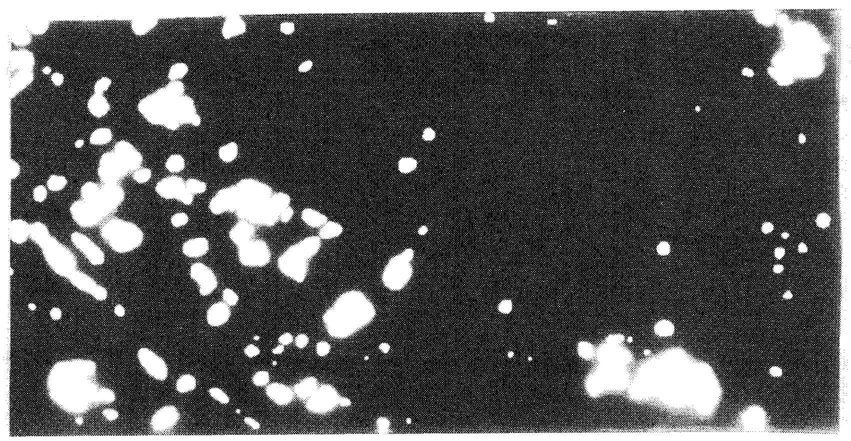


(*c*)

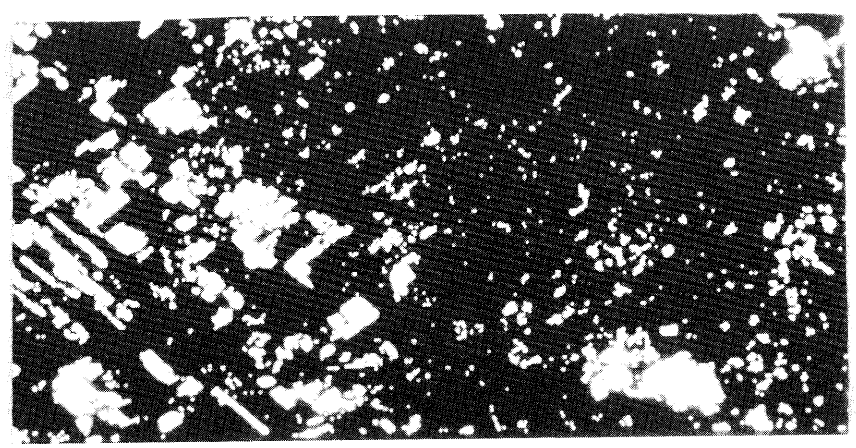
Figure 3. (*a*) The difference image from TM 3 (1986) minus TM 3 (1985); (*b*) filtered from (*a*) with a 7×7 kernel; (*c*) adaptive grey-scale mapping from (*a*) with an 11×11 kernel; (*d*) change derived from (*a*) using a threshold of plus and minus one standard deviation of



(*d*)



(*e*)



(*f*)

image (*a*); (*e*) change derived from (*b*) using a threshold of plus and minus one standard deviation of image (*b*); (*f*) change derived from (*c*) using a threshold of plus and minus one standard deviation of image (*c*).

3. Tests and results

The study area consists of a large sector of the twin cities of Kitchener–Waterloo, Ontario, Canada, and a small part of their surrounding rural area. A large number of change-detection studies have been carried out for this area with both Landsat Multispectral Scanner (MSS) and TM data (Fung and LeDrew 1987, 1988, Fung 1990). These previous studies demonstrated that, during this period, major changes occurred at the rural–urban fringe where agricultural land was either cleared for construction or has undergone crop rotation. TM data for this area were acquired on 3 August 1985 and 21 July 1986 (Path-Row No. 18-30) and were radiometrically corrected.

Illumination difference was ignored, as the two images were obtained around the same time of the year. The atmospheric difference was assumed to be horizontally homogeneous at each image acquisition time by a study area being chosen that was relatively small. With this assumption, the difference between atmospheric effects on the two images was constant throughout the study area. It only shifted the mean of the difference image. Therefore, the actual change in the difference image was not modified significantly by the atmosphere.

Part of the 1986 TM image (approximately 400×600 pixels) covering the study area was geometrically registered to part of the 1985 one using 12 ground control points. A first-order polynomial transformation with a nearest-neighbour sampling scheme was used. The standard error of geometric registration estimated from the 12 ground control points is 0·000 and 0·198 pixels across track and along track, respectively. Finally, subscenes of 250×512 pixels of the registered images were used. A black-and-white version of the colour composite of bands 2, 3 and 4 of this subscene is shown in figure 2, with the 1985 image on the top half of the illustration while 1986 one is on the bottom.

Band 3 images from both dates were used in the test. The use of the spectral range of band 3, instead of others, has been suggested by many researchers (Jensen 1981, Howarth and Wickware 1981, Jensen and Toll 1982, Howarth and Boasson 1983, Pilon *et al.* 1988, and Singh 1989). The difference image was derived by subracting the 1985 band 3 image from the 1986 one (figure 3(*a*)). An offset of 127 was added to the resultant image to shift its mean to the middle of the grey-level range between 0 and 255 such that negative grey-level values can be avoided. With the shift, the grey area in figure 3(*a*)) indicates no change, while change along with registration noise is shown in dark and light areas. At the top middle part of figure 3(*a*)), micro-structures in relative darkness and lightness inside the urban area can be observed. These are largely due to registration noise. Figure 3(*a*) was then processed by a 7×7 pixel average filter (figure 3(*b*)) and the adaptive grey-scale mapping method (figure 3(*c*)) with a filter size of 11×11 pixels. These kernel sizes have been determined through experiment. Should the size of the average filter increase, more change information would be lost. For the case of the adaptive grey-scale mapping, 11×11 is the smallest filter size that removes some obvious misregistration error, such as a dark and a white part of roads in the difference image, that should be the same target.

It can be seen from figure 3(*b*) that, although registration noise was removed, the change area was smoothed as well. Most corners of change area in figure 3(*a*) were cut out by the smoothing filter. On the other hand, it can be seen from figure 3(*c*) that most of the registration noise has been suppressed while the shapes of change areas have been preserved.

To further examine the effects of the registration-noise reduction of the two methods, change images displayed in figures 3(*d*), (*e*) and (*f*) were obtained by thresholding figures 3(*a*), (*b*) and (*c*), respectively. Thresholds were taken from the mean of each image plus and minus one standard deviation. White areas in figures 3(*d*), (*e*) and (*f*) represent changes. In figure 3(*d*), there are a large number of change areas which are relatively small in size. Although some of these areas could be real changes, such as urban reconstruction, they are largely due to the amount of registration noise in figure 3(*a*). This problem is particularly serious in the urban area. Such noise has been eliminated in figure 3(*e*). The shape of real change, however, has been seriously modified. Omission of change areas can be observed in every part of figure 3(*e*). In figure 3(*f*), a compromise between figures 3(*d*) and (*e*) has resulted where major change has been preserved very well while registration noise has been reduced. There are still some small-sized change areas, which could be either real change or registration noise.

4. Discussion and conclusion

Due to the lack of ground information on change in the study area, visual change identification was used to qualitatively evaluate the results from registration-noise reduction methods. Further work exploring the use of ground information and optimal threshold selection in the evaluation and development of registration-noise reduction algorithms is desirable.

Preliminary results of this study indicate tht the adaptive grey-scale mapping algorithm is promising for reduction of registration noise in different images. In comparison with average filters, the adaptive grey-scale mapping method does not blur the real change information.

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