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Technical Note

Use of ordinal conversion for radiometric normalization and change detection

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Change detection studies in remote sensing operate with the notion that a quantifiable difference in an object's spectral value, from one time period to another, represents a physical change on the ground. To confound this premise, other factors, such as atmospheric conditions and illumination geometry, can influence an object's spectral response. For this reason, a common first step in digital change detection is the task of image-to-image normalization. In this Technical Note, we present an efficient method for radiometric normalization of images by converting Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) pixel values into their respective ordinal ranks. To demonstrate this normalization approach, raw and ranked Landsat near-infrared (NIR) image pairs, with a 6-year lag, were differenced to detect change in forest cover located in central British Columbia, Canada. Results demonstrate that ranking values prior to image differencing improves detection of change. The ease and efficiency of the approach is promising for automation and studies of change over large areas.

1. Introduction

Remotely sensed data are increasingly used for mapping and monitoring the physical environment. One of the advantages of monitoring with remotely sensed data is that temporal sequences of images can accurately indicate environmental changes, assuming that digital values are radiometrically consistent for all scenes. Factors contributing to the potential inconsistency in measured radiance include changes in surface condition, illumination geometry, sensor calibration, observation geometry and atmospheric condition (Jensen *et al.* 1995).

Numerous radiometric normalization approaches specific to Landsat data have been documented and can be categorized as either absolute or relative. Absolute radiometric normalization techniques, which correct images independently of one another, have been applied previously in the forestry context (Häme 1991, Hill *et al.* 1995, Olsson 1995). For example, a number of radiative transfer codes, requiring scene-specific information about sensor calibration and atmospheric attenuation,

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have been developed (Tanré *et al.* 1990, Conese *et al.* 1993, Richter 1997) to address data inconsistencies specific to the effects of sensor deterioration, and atmospheric scattering and absorption. The difficulty in obtaining accurate scene-specific atmospheric and sensor parameters, however, presents relative radiometric normalization techniques as an attractive alternative (Hall *et al.* 1991, Peddle *et al.* 2003).

Relative radiometric normalization techniques may be used to correct for data inconsistencies resulting from many different effects. Several such techniques have emerged in recent years (Yuan and Elvidge 1996), the majority of which can be described as being either distribution-based or pairwise pixel-based. The latter technique commonly involves the application of linear regression to a set of subjectively chosen pseudo-invariant feature pairs (Eckhardt *et al.* 1990, Hall *et al.* 1991, Coppin and Bauer 1994) for determining a correction factor to be applied to one or more subject images in reference to a control image. Although pairwise models have been shown to perform better than distribution-based methods (Yuan and Elvidge 1996), they have the disadvantage of subjectivity in selection of pseudo-invariant features as well as sensitivity to image misregistration (Hall *et al.* 1991, Tokola *et al.* 1999). Distribution-based relative radiometric correction techniques, such as histogram matching (e.g. Chavez and MacKinnon 1994), eliminate the subjectivity problem and reduce the dependence on a geometrically accurate spatial match between multi-date images through their use of the entire dataset.

The goal of this Technical Note is to examine a procedure of radiometric normalization which does not require extensive additional information or subjective determination of relative reference values. Image normalization is carried out in one step, by converting image values to ordinal ranks. Ordinal ranking allows us to assign each pixel a new value based on its reflectance value, relative to all other pixels. When image pairs are converted to ordinal ranks the global characteristics of the distributions of pixel values are matched (Lou *et al.* 2002). Using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) imagery, we assess the ability of this normalization technique to improve the detection of anthropogenic disturbance and regeneration processes in the Morice Forest District of British Columbia, Canada.

2. Case study

The study area is centred on Tagetochlain Lake, approximately 50 km southwest of Houston, BC and is 950 km^2 in area. The dominant forest types are lodgepole pine (*Pinus contorta* var. *Latifolia*) and spruces (*Picea*), and forest age is wide ranging. Landsat TM data were acquired 7 September 1995 and ETM+ data on 15 September 2001 over cloud-free regions of the Morice Forest District (path/row: 51/22). The ETM+ image was obtained geometrically corrected (Wulder *et al.* 2002); close inspection of the image over the forest inventory polygons insured no additional geo-corrections were required. The TM image was geometrically registered to the ETM+ image using 22 ground control points with less than 0.2 pixel RMSE. A third order polynomial transformation and a cubic convolution resampling algorithm were used to determine pixel values on a 30 m grid. A top-of-atmosphere (TOA) reflectance correction based upon the procedures by Markham and Barker (1986) was applied to each Landsat image. The TOA procedure corrects for variations in solar illumination, atmospheric transmission and path radiance, and assumes a uniform atmosphere within the image. The image data are transformed from raw digital numbers to TOA reflectance values using image calibration values, radiometric ancillary information, solar zenith angle, and Earth–sun distance measurements.

For our case study, a 1024 by 1024 pixel subset of the near-infrared (NIR) band (channel 4; 0.76–0.90 μm) was used in order to eliminate minor cloud cover found in the 1995 scene (figure 1). The NIR band is useful for determining vegetation types and biomass content (Lillesand and Kiefer 2000). The NIR images for 1995 and 2001 have global mean spectral values of 52.4 and 62.8, respectively. Generally, the pixels representing lakes have the lowest values, forest corresponds to mid-range values, and exposed areas (including aging harvested areas) have the highest values. Also used in this study, are forest inventory polygons (FIPs) generated by the BC Ministry of Forests. The FIP attributes, representing 1999 forest conditions, provide information on forest species and age.

The NIR values for each image were extracted, converted to ranks, and displayed as ranked images (figures 2 and 3). Lakes are assigned the lowest ranks, forested areas have intermediate ranks, and exposed areas are assigned the highest ranks. Values that are the same are assigned tied ranks (Burt and Barber 1996).

To demonstrate the effectiveness of ranking, we carried out change detection using image differencing (2001–1995) in both the non-normalized and normalized imagery. Three types of change were anticipated: forest depletion (an increase in pixel values), forest growth (a decrease in pixel values), and no change. In the derived change images, an increase in pixel values is represented as white, black represents a decrease in digital values, and grey areas identify locations of no change (figure 4).

As hypothesized, when imagery is not normalized, change is not well detected. Both new and regenerating cut areas are represented as white (increasing pixel values) and lakes appear to change. Detecting change in the imagery normalized with ranks is more effective. Lakes do not change, and locations harvested between 1995 and 2001 are distinct and easily identified as white (increase in digital value). Even new roads, built between 1995 and 2001 are detectable (for example see the lower left corner of figure 4(*b*)). Black areas, which should indicate locations where

(*a*) (*b*)

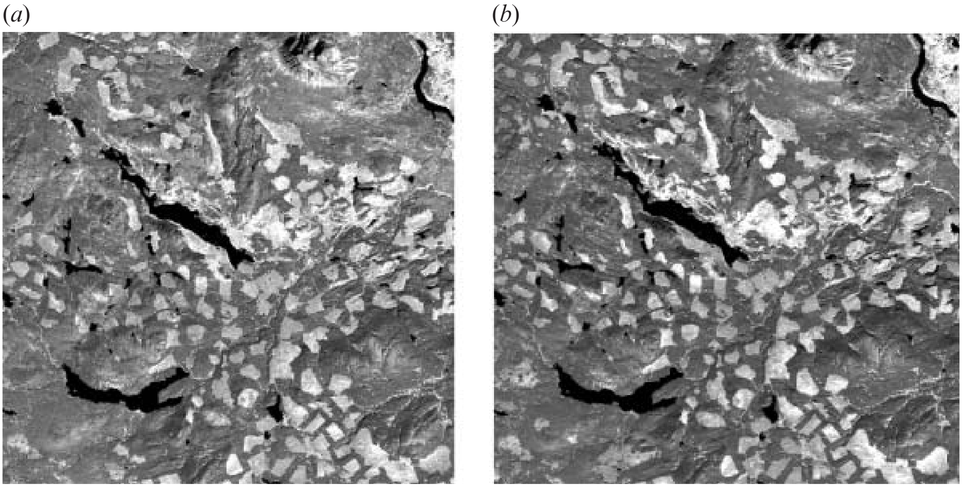

Figure 1. Landsat NIR (band 4; 0.76–0.90 μm) imagery for (*a*) 1995 and (*b*) 2001. Low values represent water, intermediate values represent forest, and high values represent exposed areas.

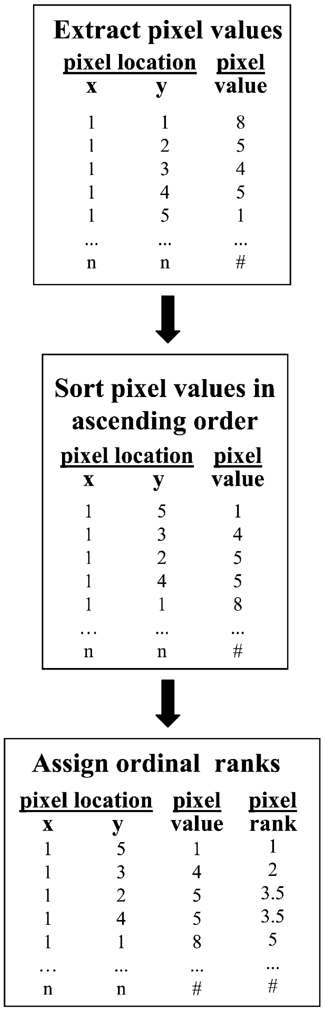

Figure 2. Overview of normalization method.

the forest cover has increased (or digital value has decreased) are less meaningful, and often occur in areas with complex topography. Subtle changes that occur over a 6-year period are difficult to detect due to factors such as compensatory increases in crown closure, growth of previously suppressed plants, and increased understorey contribution to pixel reflectance.

3. Conclusion

Image normalization and change detection via pixel ranking appears to be a promising approach; although, further investigation is required to understand its potential and limitations. For instance, it is anticipated that pixel ranking and differencing would be less effective when large-extent, 8-bit images are used; millions of pixels with only 256 possible values will result in many tied ranks.

This preliminary study has shown that ranking of digital values is a simple and effective method for normalizing imagery. Pixel ranking does not require

(a) (b)

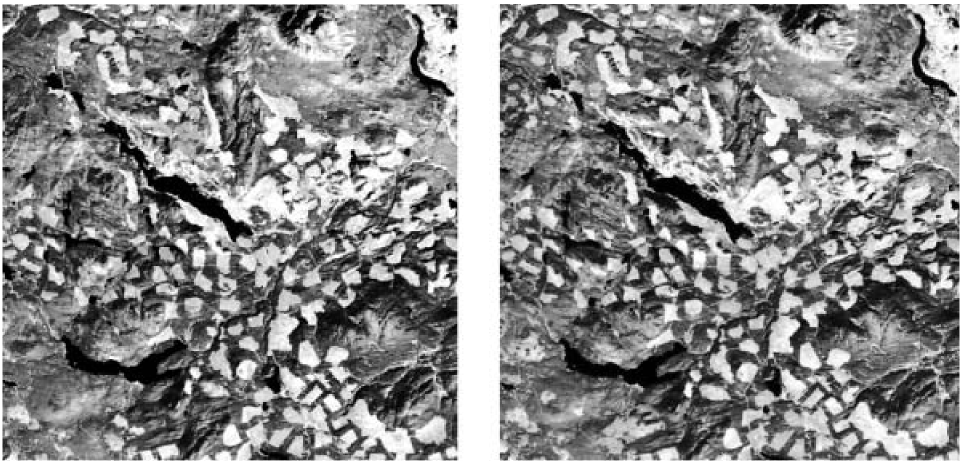

Figure 3. NIR ranked pixel values. By ranking pixels we are able to normalize imagery. Low ranks represent water, intermediate ranks represent forested areas, and high ranks represent disturbed areas. (*a*) 1995, (*b*) 2001.

(a) (b)

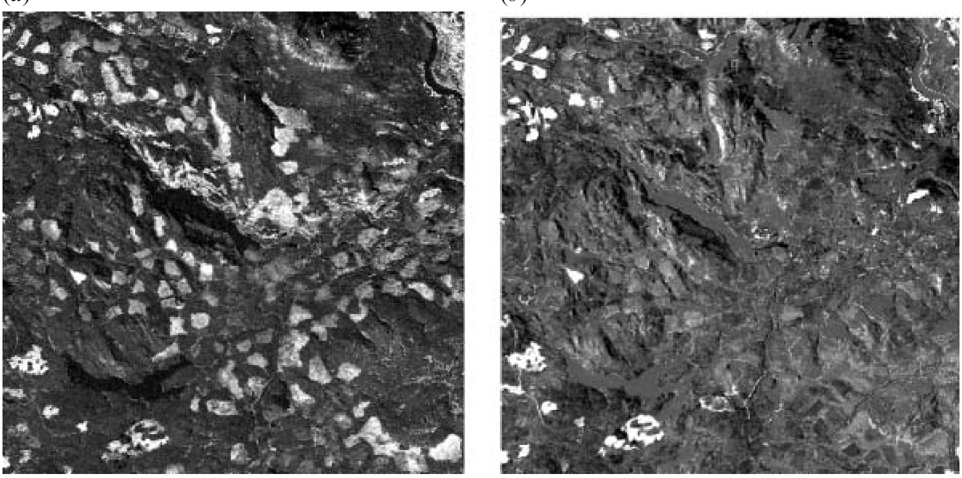

Figure 4. Results of image differencing with (*a*) non-normalized and (*b*) normalized (ranked) imagery. White areas show locations where pixel values have increased between 1995 and 2001, black areas are locations where the pixel values have decreased between 1995 and 2001, and grey areas show locations of no change.

atmospheric details, sensor information, or selection of subjective pseudo-invariant features, and therefore allows images to be simply and efficiently normalized and processed for changes with minimal *a priori* knowledge. Applications requiring the detection of change over large areas or long time series may benefit from implementation of this normalization and change detection procedure. As well, ranking may be a useful technique for normalizing imagery from multiple sensors. The simplicity and efficiency of this ordinal ranking approach may enable automation of image normalization and change detection for large area or long time series studies.

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