RADIOMETRIC NORMALIZATION OF IKONOS IMAGE USING QUICKBIRD IMAGE FOR URBAN AREA CHANGE DETECTION

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ABSTRACT:

Remotely sensed multitemporal, multisensor data are often required for change detection applications. A common problem associated with the use of these data is the grey value difference caused by non-surface factors such as different illumination, atmospheric, or sensor conditions. Such a difference makes it difficult to accurately detect changes using automatic methods. Effective image normalization is, therefore, important to reduce the radiometric influence caused by the non-surface factors and to ensure that the grey value difference between two temporal images reflects actual changes on the surface of the Earth.

A variety of image normalization methods, which include pseudo-invariant features (PIF), dark and bright set (DB), simple regression (SR), no-change set determined from scattergrams (NC), and histogram matching (HM), have been published in scientific journals. These methods have been tested with either Landsat TM data, MSS data or both, and show different results varying from authors to authors. However, whether the existing methods would be adopted for normalizing currently available high resolution multispectral satellite images, such as IKONOS and QuickBird, the question is still open because of the drastic change in spatial resolution and difference of available multispectral bands. In this research, the existing methods are introduced and employed to normalize the radiometric difference between IKONOS and QuickBird multispectral images taken in different years. Some improvements are introduced to overcome problems caused by band difference and to achieve more stable and better results. The normalized results are compared in terms of visual inspection and statistical analysis.

1. INTRODUCTION

Image normalization is very important in automatic change detection process. Multitemporal images will have the same color metric system after image normalization. It can be more difficult to quantify and interpret changes on multitemporal images under different illumination, atmospheric, or sensor conditions without radiometric calibration. Although many changes can be detected without applying a radiometric calibration, in order to identify automatically what the detected changes are, even in a general sense, image normalization becomes critical (Chavez and Mackinnon, 1994). Image normalization applies one image as a reference and adjusts the radiometric properties of subject images to match the reference (Hall et al., 1991; Yuan and Elvidge, 1996). Normalized images appear to have been acquired with the reference image sensor under atmospheric and illumination conditions equal to those in the reference scene (Hall et al., 1991).

IKONOS and QuickBird are two popular types of high resolution satellite images. They are often used in monitoring land use and land cover and often used together. In such a case, the matter of comparability and continuity between QuickBird and IKONOS is important for many monitoring-related applications. However, most published papers on image normalization are based on Landsat TM or MSS data. The purpose of this study is to find strategies that can be effective in normalizing the IKONOS image using the QuickBird as a reference. These strategies used existing image normalization techniques based on spectral comparability and continuity between the IKONOS and QuickBird images. The paper will provide readers with useful information on whether existing methods can be directly adopted for image normalization with very high resolution satellite images and some suggested improvements.

2. EXISTING RADIOMETRIC NORMALIZATION METHODS

The process of image normalization can be divided into two steps: (1) selecting normalization targets; and (2) determining normalization coefficients.

2.1 Normalization target selection

Some methods have been introduced by different authors showing how to select the ideal targets to estimate the normalization transformation coefficients (Schott et al., 1988; Eckhard et al., 1990; Hall et al., 1991; Elvidge et al., 1995). The targets that meet the following criteria are selected as ideal targets for normalization (Eckhardt et al., 1990):

1. The targets should be approximately at the same elevation.

2. The targets should contain only minimal amounts of vegetation.
3. The targets must be in relatively flat areas.
4. When viewed on the image display screen, the patterns on the normalization targets should not change over time; and a set of targets must have a wide range of grey values for the regression model to be reliable.

2.2 Normalization coefficients determination

1. Simple Regression (SR) method
   Simple regression normalization (Jensen, 1983) uses the least-squares equation to derive normalization coefficients.
2. Histogram Matching (HM) method
   Histogram matching is a common image processing method for radiometric enhancement. It uses the reference image histogram to modify the subject image histogram distribution.
3. Pseudo-invariant Feature Set (PIF) method
   Schott et al. (1988) presented pseudo-invariant feature normalization, which analyzed the elements whose reflection distribution has statistical invariance, such as concrete, asphalt and rooftops. Those elements are assumed not to have any significant change between two acquisition dates. Differences in the gray-level distributions of these invariant objects are supposed to be linear and are corrected statistically to perform the normalization.
4. Dark-Bright (DB) method
   Hall et al. (1991) used the average of a set of dark and bright pixels (dark-bright set -simply called DB), which are extracted from the subject and reference image through Kauth-Thomas greenness-brightness transformation, to derive the normalization coefficients. It is assumed that an image always contains at least some pixels that have the same average surface reflectance among images acquired at different dates.
5. No Change Set (NC) method
   Elvidge et al. (1995) developed a radiometric normalization method (no-change pixel set) through a no-change set determined from the scattergram between near-infrared bands of the subject image and the reference image. Pixels falling within the no-change region will be used to compute normalization coefficients for all bands.

3.NORMALIZATION OF THE IKONOS IMAGE WITH THE QUICKBIRD IMAGE — DIFFICULTIES AND NEW SOLUTIONS

Due to differences in spatial resolution, spectral band and radiometric resolution between Landsat and IKONOS/QuickBird images, not all the existing methods can be directly applied to the normalization of IKONOS or QuickBird images. For example, some methods require the middle infrared band to determine normalization coefficients. However, this band is not available in the new high resolution multispectral data sets. Therefore, difficulties were incurred during the testing normalization methods and as a result new solutions were introduced. The detailed implementation of each method for normalizing IKONOS and QuickBird data are described below:

1. The SR method and the HM method

The SR method and the HM method both use all pixels of the reference image and the subject image in the normalizing image process. No complicated normalized target selection is involved in both methods. There is no significant difference in implementing these methods between different satellite data.

2. The PIF method

The pseudo-invariant feature set for the PIF method is defined by eq. (1) and eq. (2).

For IKONOS image:

$$\text{PIF set} = \left\{ \frac{\text{band4}}{\text{band3}} < 2 \quad \text{and} \quad \text{band4} > 80 \right\} \qquad (1)$$

For QuickBird image:

$$\text{PIF set} = \left\{ \frac{\text{band4}}{\text{band3}} < 2 \quad \text{and} \quad \text{band4} > 140 \right\} \qquad (2)$$

Because the data set is different from previous research published by other authors (Schott et al., 1988; Eckhard et al., 1990; Hall et al., 1991; Elvidge et al., 1995; Yuan and Elvidge, 1996; Yang and Lo, 2000), the empirical values supported by those authors cannot be used in this study.
The results of this method tested by Yuan and Elvidge (1996) and Yang and Lo (2000) were not good. In this study, the normalized image and the reference image appears very different by directly using these pseudo-invariant feature sets derived from eq. (1) and eq. (2). After analyzing the pseudo-invariant feature sets, the problem lies with that some floating objects in the river whose reflectance is similar to roof tops, roads and others are included in the pseudo-invariant feature sets. Those objects cannot be included into invariant change objects in the pseudo-invariant feature set because they don't fit in with the method's assumption, which is the selected normalization targets are assumed not to have any significant change between two acquisition dates. In such a case, a special mask excluding all water area is required to refine the pseudo-invariant feature sets. After it is refined, the number of these pseudo-invariant feature sets is changed from 1629789 to 1543225 in the Quickbird image, from 1703930 to 1690168 in the IKONOS image. The normalized image is very similar to the reference image using refined pseudo-invariant feature sets, although it cannot compare with the other methods.

3. The DB method
   The greenness and brightness transformation formula is different between Landsat TM image or MSS image and QuickBird image or IKONOS image. Horne (2003) developed a set of translation coefficients for IKONOS image:

$$\text{brightness} = 0.326x_{blue} + 0.509x_{green} + 0.560x_{red} + 0.567x_{nir} \qquad (3)$$
$$\text{greeness} = -0.311x_{blue} - 0.356x_{green} - 0.325x_{red} + 0.819x_{nir}$$

There is no special transformation formula for QuickBird data. Considering it is similar to the IKONOS image in both spectral range and radiometric resolution, eq. (3) is also applied to QuickBird image for this study. Both the dark set and bright set are defined using eq. (4) and eq. (5).
Eq. (4) is applied to the IKONOS image:

$$\text{Dark set} = \{ greeness \le 1 \quad and \quad brightness \le 300 \} \qquad (4)$$

and Bright set= { $greeness \le 1 \quad and \quad brightness \ge 300$ }

Eq. (5) is applied to the QuickBird image:

Dark set={ $greeness \le 1 \quad and \quad brightness \le 190$ } (5)
and Bright set= { $greeness \le 1 \quad and \quad brightness \ge 220$ }.

All the values appeared in eq. (4) and eq. (5) are obtained by comparing based on different experiments' results. All the empirical values appeared in the previous publication have no reference value in this study.

4. The NC method
Because IKONOS and QuickBird only have one Near-IR band, it makes them unlike MSS and Landsat satellite data. Thus, there is one limited condition to find the no-change pixels in the scattergram between Near-Infrared bands. In this study, one band Near-IR works very well.

The NC set is defined by the following equation (eq. (6)).

NC set= $\{ |Y_4 - a_{40} X_4 - b_{40}| \le HVW \}$ (6)

In eq.(6), a_{40} and b_{40} are initial normalization coefficients for the Near-Infrared band normalization coefficients (a_4 and b_4) through locating the centers of water and land-surface data clusters from Near-Infrared band—band 4 scattergram. HVW is the corresponding half vertical width of the no-change regions in the scattergrams. HVW can be acquired by eq.(7).

$$HVW = \sqrt{1 + a_{40}^{2}}\,(HPW) \qquad (7)$$

Where a_{40} is the initial normalization coefficients of band 4, HPW is the half perpendicular width which is set as 10 in this study.

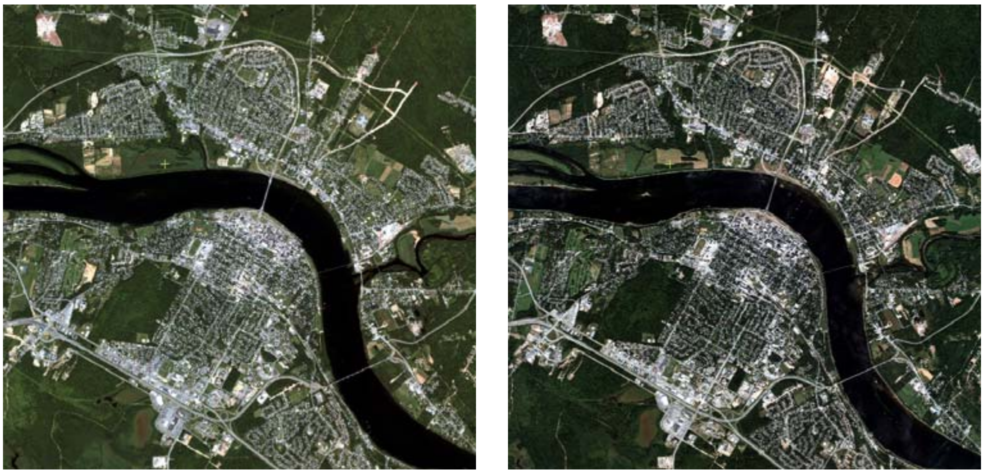
The normalization coefficients are calculated and listed in Table 1.

Method	Band 1		Band 2		Band 3		Band4	
	a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
SR	0.485	32.242	0.601	44.882	0.518	20.507	0.575	88.142
PIF	0.867	-88.605	1.062	-107.218	0.912	-80.272	0.925	-80.608
DB	0.623	-0.679	0.760	12.766	0.638	6.921	0.747	-3.085
NC	0.554	14.766	0.671	28.856	0.579	12.832	0.719	2.913

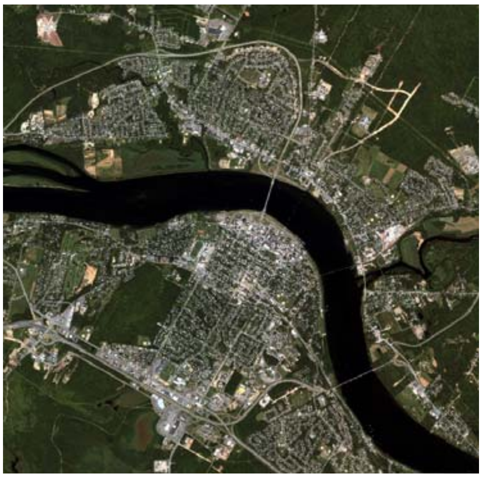
Table 1. The normalized coefficients for different normalized methods

4. RESULTS

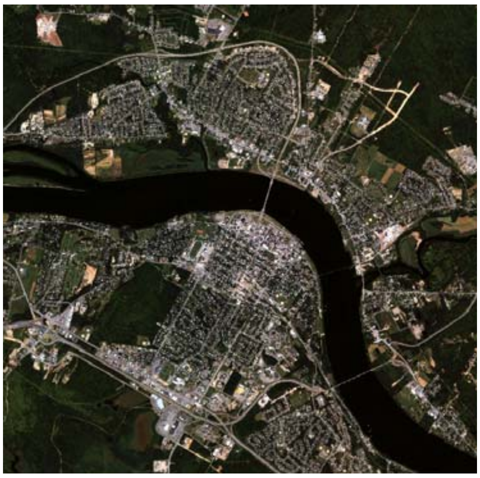
The original QuickBird, IKONOS and normalized images are shown in Figure 1. In terms of visual inspection, the HM is closest to reference image－the QuickBird image. The SR, NC and DB look similar; it is difficult for the naked eye to distinguish which one is the best from these three normalized images. They are all similar to the reference image. Compared with the other results, the PIF normalized image is the least satisfying, but it is still acceptable.



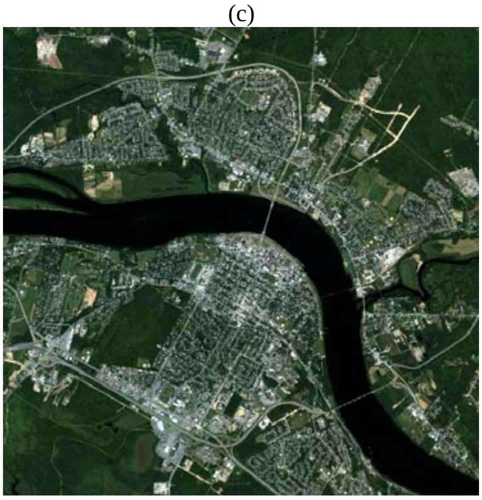
(a) (b)



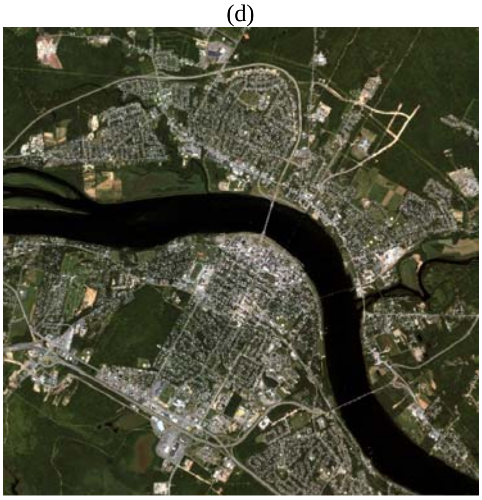
(c)



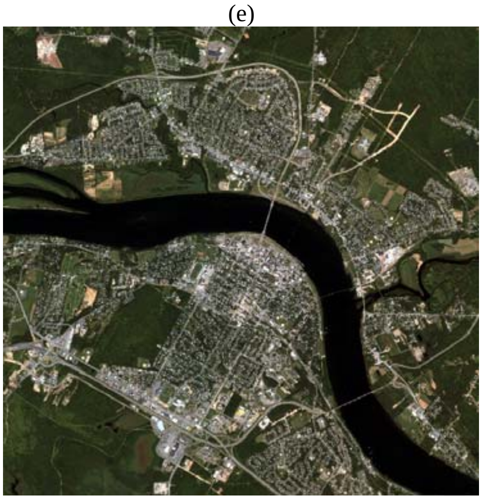
(d)



(e)



(f)



(g)

Figure 1 the reference image, the subject image and normalized images
(a): Original IKONOS image as the subject image; (b): Original QuickBird image as the reference image; (c): SR normalized IKONOS image; (d): HM normalized IKONOS image; (e): PIF normalized image; (f): DB normalized IKONOS image; (g): NC normalized IKONOS image.

The root mean square error (RMSE) is used to evaluate the normalized images statistically. The root mean square error and sample sizes are listed in Table 2. In the table, the original data average RMSE is 118.98, all the normalized images' average RMSE are less than this, this implies that the normalized image is radiometrically more similar to the reference image. Different methods can be ranked according to their average RMSE value in descending order of HM, SR, NC, DB and PIF. The average RMSE difference is not significant among SM, NC and DB methods. These small differences underscore that distinguishing between them visually is difficult.

Method	Radiometric control sets in IKONOS		Radiometric control sets in QuickBird		Root Mean Square Error				
	Number	%	Number	%	Band1	Band2	Band3	Band4	Average
RAW*	7639212	100	7639212	100	115.18	90.82	96.57	173.35	118.98
SR	7639212	100	7639212	100	30.39	53.41	48.06	125.34	64.3
HM	7639212	100	7639212	100	20.12	45.34	39.16	98.67	50.82
PIF	1690168	22.12	1543225	20.20	42.36	70.04	65.55	138.92	79.21
DB	895445(**D***) 1226286(**B***)		710399(**D***) 1133372(**B***)						
	2121731(**T***)	27.74	1843771(**T***)	24.13	32.77	57.47	53.25	128.03	67.88
NC	1240017	16.23	1240017	16.23	31.67	54.88	51.58	127.32	66.36

Table 2. Sample size and root mean square error of different normalization methods
* D: dark set; B: bright set; T: total pixel number; RAW means between the subject image and the reference image

5. CONCLUSION

This study has investigated the typical image normalization methods in normalizing the IKONOS image with the QuickBird image. In this study, the findings of this research are:

1. Refining the PIF set yields a reasonable result. This result differs from the negative experience of previous published studies (Yuan and Elvidge, 1996; Yang and Lo, 2000);
2. In DB method provides a good result through introducing the empirical brightness and greenness transformation formula, although there is no special brightness and greenness transformation formula for the QuickBird image;
3. In the NC method, only using Near-IR one band, it is also possible to define no change area sets and to obtain a good result.

In terms of normalization effect, HM is the best, followed by SR, NC, DB and PIF.

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