

Relative Radiometric Correction of Cloudy Multitemporal Satellite Imagery

Seema Biday, Udhav Bhosle

Abstract—Repeated observation of a given area over time yields potential for many forms of change detection analysis. These repeated observations are confounded in terms of radiometric consistency due to changes in sensor calibration over time, differences in illumination, observation angles and variation in atmospheric effects.

This paper demonstrates applicability of an empirical relative radiometric normalization method to a set of multitemporal cloudy images acquired by Resourcesat1 LISS III sensor. Objective of this study is to detect and remove cloud cover and normalize an image radiometrically. Cloud detection is achieved by using Average Brightness Threshold (ABT) algorithm. The detected cloud is removed and replaced with data from another images of the same area. After cloud removal, the proposed normalization method is applied to reduce the radiometric influence caused by non surface factors. This process identifies landscape elements whose reflectance values are nearly constant over time, i.e. the subset of non-changing pixels are identified using frequency based correlation technique. The quality of radiometric normalization is statistically assessed by R^2 value and mean square error (MSE) between each pair of analogous band.

Keywords—Correlation, Frequency domain, Multitemporal, Relative Radiometric Correction

I. INTRODUCTION

SATELLITE images are useful for monitoring changes in land use and land cover. But major problem with these images is that regions below clouds are not covered by sensor. The image distortion due to cloud cover is a classical problem of visible band of remote sensing imagery. Especially, for non-stationary satellite, it is commonly found in the earth resource observation application. Removing cloud cover from satellite imagery is very useful for assisting image interpretation. Hence cloud detection and removal is very vital in processing of satellite imagery. Further it is more difficult to quantify and interpret changes on multitemporal images under different illumination, atmospheric or sensor conditions without radiometric calibration. The relative approach to radiometric correction, known as relative radiometric normalization, is preferred because no *in situ* atmospheric data at the time of satellite overpasses are required [1].

There are many possible approaches to achieve radiometric correction. One set of methods calibrate the images to standard reflectance units by using atmospheric radiative transfer code [2], relating image spectral curves to laboratory spectral curves [3], or using dark objects and atmospheric radiative transfer code [4]. Further methods perform scene correction by dark-object subtraction [5], scene-to-scene correction by histogram normalization [6], scene-to-scene correction using dark and bright targets [7] or Pseudo-Invariant Features (PIFs) [8]. Relative radiometric normalization is a method of correction that considers one image as a reference and adjusts the radiometric properties of subject images [7], [9].

Here two satellite images are used, which are acquired at different time and different cloud distribution. The cloud is detected by Average Brightness Thresholding (ABT) algorithm. This is followed by relative radiometric normalization of the image. Here correlation procedure implemented in frequency domain is used for identification of non-changing pixels. This approach is chosen because of its intrinsic simplicity than other methods.

The paper is organized as follows. Section 2 deals with data and study area. Section 3 describes technique of cloud removal. Section 4 describes radiometric normalization applied on cloud free subject image. Section 5 presents experimental results and conclusion in section 6.

II. DATA AND STUDY AREA

The image dataset used in this study is obtained from Resourcesat1 LISS III sensor. The RESOURCESAT-1 (IRS-P6) satellite launched on October 17, 2003 is designed to provide multispectral, monoscopic and stereoscopic images of the earth's surface. It has LISS-III multi-spectral camera operating in four spectral bands, two in the visible and near infrared and one in SWIR region, as in the case of IRS-1C/1D. The new feature in LISS-III camera is the SWIR band (1.55 to 1.7 microns), which provides data with a spatial resolution of 23.5m unlike IRS-1C/1D in which the spatial resolution is 70m [courtesy:-www.nrca.gov.in.].

Fig. 1(a) shows original Resources at LISS III reference image and Fig. 1(b) shows cloudy subject image which is to be radiometrically corrected with respect to the reference image.

III. CLOUD REMOVAL

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Detection of cloud is achieved by average brightness thresholding (ABT) algorithm [14].

Average brightness thresholding algorithm is based on three observations:

1. Amplitude thresholding is simple to implement and provides quick processing.
2. When correct threshold level(s) are chosen, amplitude thresholding is highly effective.
3. Clouds are usually the brightest objects in satellite image.

The algorithm is quite simple to implement. First, the average brightness of the grayscale image is calculated. Next, a threshold brightness is chosen based on the average brightness. Finally this threshold is applied to the image to divide it into cloudy and cloud free regions. The detected cloud is removed and replaced with data from another image of same area. The procedure is repeated for all bands.

ABT uses an average-cutoff function to determine appropriate brightness threshold level. This function has the characteristic that at low average brightness levels, cutoff is very much above the average, whereas at high average brightness levels, the cutoff is marginally above average brightness.

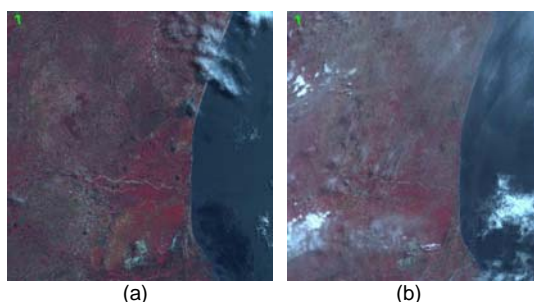


Fig. 1. (a) Reference Image (11 May 2004), (b) Subject image (26 May 2006)

We define cutoff function as

$$\text{Cutoff} = \text{Avg_Brightness} + f \times (\ln(\text{G_MAX}) - \ln(\text{Avg_Brightness}))$$

where $\ln(\)$ denotes the natural logarithm

G_MAX is the number of grayscale values, in this case $\text{G_MAX} = 256$

f is multiplicative coefficient, determined empirically, in this case, $f = 22$

Experimental results are presented for the case of cloud contaminated Resourcesat LISS III image acquired in 2006. This image is corrected successfully by using ABT algorithm with the aid of a reference image from 2004. Fig. 2 shows detected cloud region and image after cloud removal. Fig. 3 shows histograms of image before and after cloud removal.

IV. NORMALIZATION METHOD

Relative radiometric correction is a method of correction that applies one image as a reference and adjusts the radiometric properties of subject image to match the reference [6], [9].

After removal of cloud from subject image, radiometric normalization is applied on cloud free subject image. Following assumptions are made.

1. Camera parameters are not known.
2. Imaging conditions are not known.

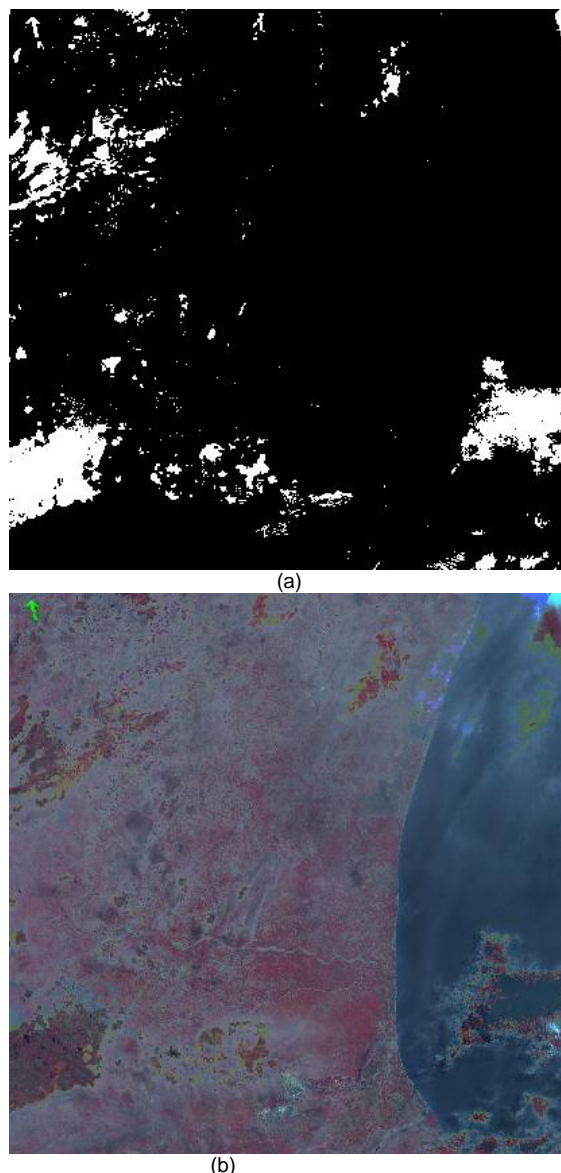
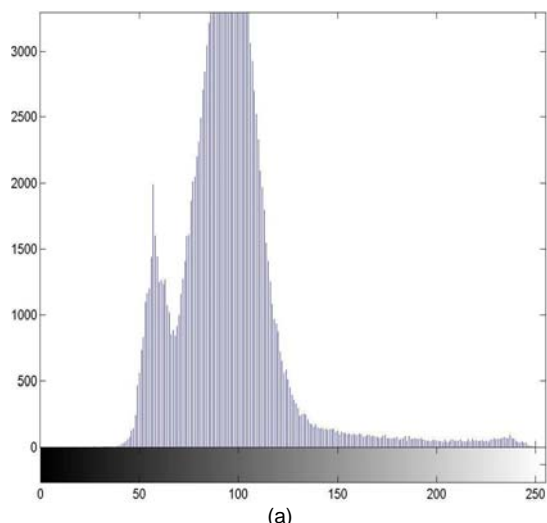
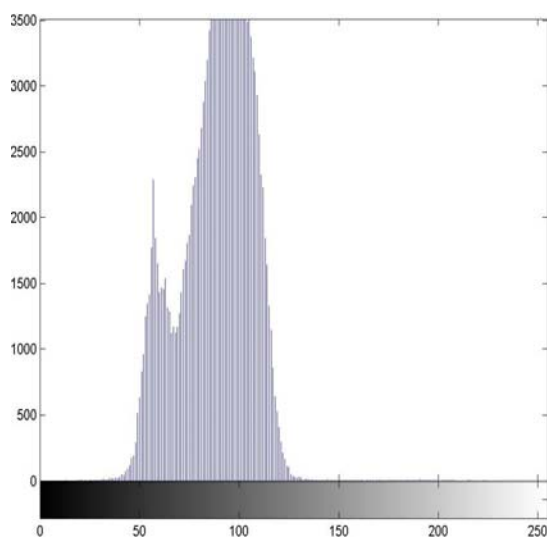


Fig. 2 Cloud detection and removal by using ABT. (a) Detected cloud area in image (26 May 2006), (b) Image (26 May 2006) after cloud removal



(a)



(b)

Fig. 3 (a) Histogram of Cloudy Subject Image, (b) Histogram of Cloud Free Subject image.

Hall's concept of radiometric rectification is based on stable reflectance control sets derived from the extremes of the image scattergram [6]. Other methods use stable reflectance targets or so-called pseudo-invariant features [7]. Some approaches interpret changed pixels as outliers, and adopt a strategy to eliminate, or attenuate them.

To identify no-change pixels, correlation in frequency domain is used. The reference image and subject image are divided into rectangular blocks of size 16x16 pixels. Blocks or extracts of image were used in a procedure that processes images from different dates band to band. A block of reference image is placed over block centered on the same coordinates in the other image. Then, normalized correlation between two corresponding blocks is calculated. This operation is repeated for all blocks. This procedure is repeated for all bands. After this, we applied a threshold criterion, in order to select no-change pixels, used to find normalization coefficients. A block is assumed to belong to the no-change set if it has normalized correlation in all bands greater than 0.9.

Correlation can be calculated as,

$$f(m,n) \circ w(m,n) = \mathcal{F}^{-1}[\mathcal{F}(u,v) W^*(u,v)] \quad (1)$$

where $f(m,n)$ is block of 16x16 pixels of reference image

$w(m,n)$ is block of 16x16 pixels of subject image

m,n are spatial co-ordinates.

$F(u,v)$ and $W(u,v)$ represent fourier transform of $f(m,n)$ and $w(m,n)$ respectively.

\mathcal{F}^{-1} denotes inverse Fourier transform

\circ denotes correlation

$*$ denotes the complex conjugate.

Normalised Correlation is defined as

$$NC = \mathcal{F}^{-1}[\mathcal{F}(u,v) W^*(u,v)] / \max(\mathcal{F}^{-1}(W(u,v) W^*(u,v))) \quad (2)$$

The DN values of no-change set are then used in a linear model as

$$\hat{y}_k = a_k x_k + b_k \quad (3)$$

where x_k the DN of band k in image X on date1, y_k the DN of band k in image Y on date2, y'_k is the normalized DN of band k on date1, and a_k, b_k are normalization constants for band k.

A normalization line is constructed using a subset of image i.e. no change pixel set NC. The normalization coefficients can be obtained by solving the least-squares regression equation,

$$Q = \sum_{NC} (y_k - a_k x_k - b_k)^2 = \min \quad (4)$$

to obtain the coefficients

$$a_k = \frac{\sum_{(nc)}^{(nc)} x_k y_k}{\sum_{(nc)}^{(nc)} x_k x_k}, \quad b_k = \bar{y}_k^{(nc)} - a_k \bar{x}_k^{(nc)} \quad (5)$$

$$\text{where } S_{x_k x_k}^{(nc)} = \frac{1}{|NC|} \sum_{NC} (x_k - \bar{x}_k^{(nc)})^2 \quad (6)$$

$$\text{and } S_{x_k y_k}^{(nc)} = \frac{1}{|NC|} \sum_{NC} (x_k - \bar{x}_k^{(nc)})(y_k - \bar{y}_k^{(nc)}) \quad (7)$$

are the sample variance and covariance for the subset NC on two dates. $|NC|$ is the number of pixels in the set NC.

V RESULTS AND DISCUSSION

The quality of radiometric normalization can be statistically assessed with the use of R^2 value and Mean Square Error (MSE) between each pair of analogous bands.

The MSE is defined as,

$$MSE = \frac{1}{n} \sum_{k=1}^n (\hat{y}_k - y_k)^2 \quad (8)$$

The R^2 value is defined as,

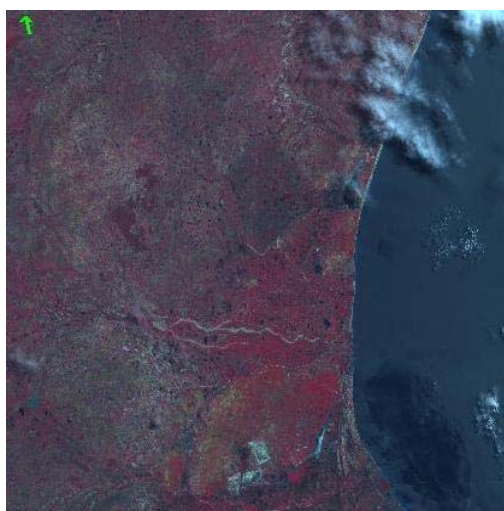
$$R^2 = \frac{\sum_{k=1}^n (\hat{y}_k - \bar{y}_k)^2}{\sum_{k=1}^n (y_k - \bar{y}_k)^2} \quad (9)$$

where n is total number of pixels in the scene.

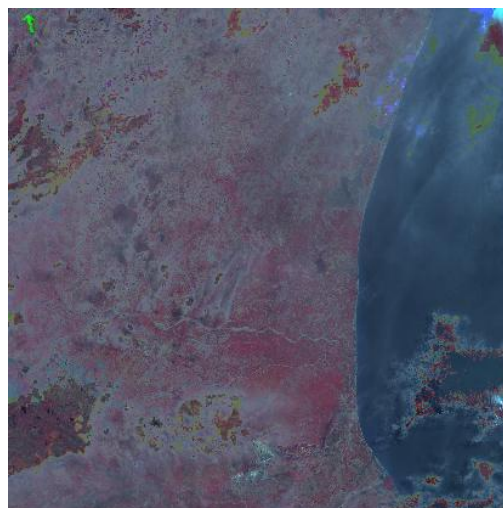
Closer the R^2 value to one, better the radiometric process. MSEs and R^2 values are listed in Table II. Results show that MSEs of all bands of normalized image are less than uncorrected image and improvement in R^2 value. This implies that normalized image is more similar to the reference image. Fig. 4(a) shows cloud free subject image which is to be radiometrically corrected with respect to the reference image. Table I provides normalization coefficients determined by proposed method. Set of normalization coefficients are applied to data set and resulting normalized image is shown in Fig. 4(c).

VI. CONCLUSIONS

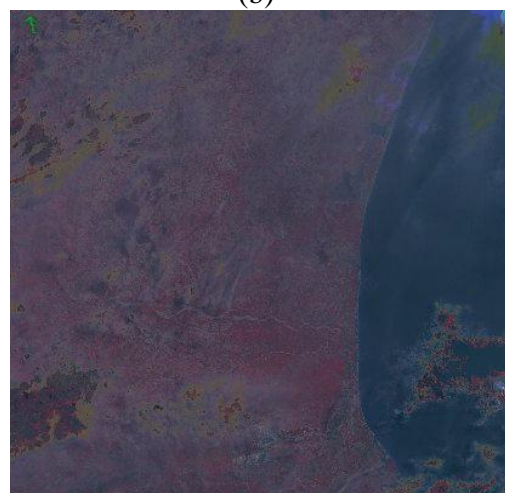
In this paper, a technique for relative radiometric correction of cloudy multitemporal satellite images has proposed. The proposed scheme successfully normalize cloudy subject image. However, it highly depends on spatial registration between the two images (reference image and cloudy subject image).



(a)



(b)



(c)

Fig. 4 Radiometric normalization using correlation in fourier domain (a) Reference Image, (b) Subject image after cloud removal, (c) Normalized image

TABLE I
THE NORMALISATION COEFFICIENTS

Band	ak	bk
Band1	-0.00068	0.9958
Band2	0.00012	0.9836
Band3	0.00073	0.9760
Band4	0.00034	0.9732

TABLE II
MSEs AND R^2 VALUES

Band	MSE	R^2
Before normalisation		
Band1	31.0989	0.76
Band2	41.5586	0.63

Band3	44.4377	0.48
Band4	44.3221	0.44
After normalisation		
Band1	14.1285	0.85
Band2	15.6910	0.83
Band3	18.0103	0.78
Band4	15.9433	0.82

Proposed method of radiometric normalization has following advantages.

- [1] Computing correlation in the frequency domain using the fast Fourier transform is more efficient than in spatial domain.
- [2] Distribute normalization error among different land-cover types.
- [3] Eliminate the necessity of identifying bright and dark radiometric control pixels.
- [4] Accelerate the speed of the normalization procedure. It does not require the presence of both land and water areas in the satellite images.
- [5] The results are less sensitive to outliers in the data.

Future scope includes use of image segmentation using region growing technique, 2-D histogram method to detect the cloud cover. In this method, the detected cloud is removed and replaced with data from another image of the same area. Instead of this, the pixels in cloud removed area can be replaced with estimated pixel values obtained from regression.

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