THE PRECISION ASSESSMENT OF DIFFERENT SPACE OPTICAL REMOTE SENSING IMAGE RELATIVE RADIOMETRIC CORRECTION METHODS

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ABSTRACT: Due to the different response among detectors, the odd/even effect raised in signal transfer and the inconsistency of electronic links, obvious vertical strip noise and chromatic aberration exist in the raw image acquired by space optical remote sensing sensors. There is need to correct the non-uniformity of the detector outputs and normalize the DN value of raw images during the remote sensing ground station preprocessing program in order to produce the radiometric correction production. Relative radiometric correction as one of the most important steps in the process of remote sensing image production, many remote sensing researchers have investigated how to remove the vertical strip noise and correct the chromatic aberration and presented several space optical remote sensing relative radiometric correction methods since the successful launch of LANDSAT-1 in 1972. In the paper, the different relative radiometric correction methods, such as calibration coefficient, histogram equalization, histogram matching, neighbor column equalization, Fourier transform (FT), finite impulse response (FIR) filter and wavelet transform, are introduced in the first. Secondly, taken the Beijing-1 small satellite multi-spectral and panchromatic raw images as example, using these methods to relative radiometric correct the raw images. And then, the three relative radiometric correction precision assessment methods, neighbor column difference, generalized noise and stripe ration, are discussed in detail and used to assess the radiometric correction precision. At last, according to the results of precision assessment, the suitable relative radiometric correction methods for removing the strip noise and correcting chromatic aberration are given.

1. Introduction

The raw images acquired by the space optical CCD remote sensor contain obvious vertical strip noise due to the radiometric error, such as the different responsibility between the odd and even detectors, the inconsistency of external electronic links and detector defect, etc. In the remote sensing data processing chain, the radiometric error must be removed so that the value-added image can be processed accurately. Relative radiometric correction as one of the most important remote sensing image processing methods that are applied to correct the radiometric difference of CCD detectors output signal by normalizing its original digital number (DN) values.

The aim of relative radiometric correction is to remove the vertical stripe noise and smooth the chromatic aberration and then generate the radiometric correction production during the procedure of space optical CCD remote sensing data preprocessing. The relative radiometric corrected image is the original earth observation data for absolute radiometric calibration and quantitative remote sensing application (Guo, et al., 2005).

Currently, there are three types of relative radiometric correction methods, such as using calibration site images to calculate the gain and bias coefficient and statistical methods based on the image itself and the low-pass filter. According to the low-pass filter methods, the strip can be looked as periodic noise with high frequencies and can be removed by filter in frequency or spatial domain (Chen, et al., 2003). In this paper, the Beijing-1small satellite multi-spectral and panchromatic raw images are taken as examples to assess the precision of different relative radiometric correction methods. These different methods are calibration coefficient (Gao, et al., 2009), histogram equalization (Guo, et al., 2005), histogram matching (Pan, et al., 2005), neighbor column equalization (Zhang, et al., 2006), Fourier transform (E, et al., 2004), finite impulse response filter (Chen, et al., 2004) and wavelet transform (Chen, et al., 2003; Jiang, et al., 2003).Three radiometric correction precision assessment methods of neighbor column difference, generalized noise (Hu, et al., 2007) and stripe ration (Samer l., 2003) are used to quantitatively analyze the accuracy of different correction methods and advise which relative radiometric correction method should be used in ground station preprocessing of space optical remote sensing raw imagery.

2. Methods of Relative Radiometric Correction

2.1Calibration Coefficient Method

Calibration coefficient method is based on the hypothesis that the response of CCD detector is linear in the remote sensor dynamic range. The calibration coefficients calculated by using calibration ground site images are applied to correct the odd and even stripe noise existed in raw image. The calibration coefficients contain gain and bias coefficient. The correction model as follows:

$$CND_i = {(DN_i - B_i)}/{G_i} \tag{1}$$

Where CND_i is the radiometric corrected DN value and ND_i is the original DN value of the i-th detector. B_i is the bias of the i-th detector which usually refer to the remote sensor CCD detector's dark current output and the G_i is the gain.

The gain and bias coefficients of each detector of linear CCD array are generated by using the homogeneous radiometric scene image. For on-orbit remote sensing satellite, the snowy landscape and desert are generally looked as the homogeneous radiometric scenes which are used to calculate the radiometric correction coefficients. The method of gain and bias coefficients generated basis on calibration site images is called calibration coefficient method. The formula of how to calculate gain coefficients through the calibration site images is below.

$$G_i = {(\overline{DN_i} - B_i)}/{DN'} \tag{2}$$

Where, $\overline{DN_i}$ is the mean DN value of the i-th column raw image which represents the output of the i-th detector. B_i is the dark current of the i-th detector's output and DN_i is the mean value of the whole raw image.

2.2 Statistical Method

1）Histogram equalization

Based on the hypothesis that the gray value of each detector has the same distribution probability and the camera system has good linear responsibility, the histogram equalization method calculates the gain and bias by using the DN value of the image itself. The equations of calculating gain and bias coefficients are as follows.

$$G_i = {\sigma_i}/{\sigma_R} \qquad B_i = \mu_i - \mu_R \cdot \frac{\sigma_i}{\sigma_R} \tag{3}$$

Where, σ_i is the standard deviation of the i-th column of raw image and σ_R is the standard deviation of the whole image. μ_i is the mean of the i-th column of raw image and μ_R is the mean of the whole image.

2）Histogram matching

The method of histogram matching is to calculate the histogram of the image as the expectation histogram firstly, and then calculate the histogram of each column of image. Histogram lookup table of each detector are estimated via matching the histogram of each column to the expectation histogram. When the histogram matching method is used to relative correct radiometric error, there is need to apply numbers of raw images to calculate the proper gain and bias coefficients.

3）Neighbor column equalization

Neighbor column equalization method considers that the strip noise in the image will change the slow variation of the mean and standard deviation of column image between the neighbor column images. And the strip noise will make the mean and standard deviation of column image undulated with the alternation of odd detector and even detector. This method smoothes the undulation of column mean and column standard deviation by using 1-dimension average filter. The smoothed column mean and standard deviation are regarded as the column mean and standard deviation of the corrected image. Then, the gain and bias can be calculated and used to correct the striping image.

2.3 Filter Methods

1）Fourier transform

Traditional Fourier transform method transforms images to frequency domain and removes the high frequency strip noise by using low-pass filter in the frequency domain. And the stripe removed image is generated through inverse Fourier transform. Eq. (4) is the frequency domain destriping equation.

$$F'(u) = F(u) * H(u) \tag{4}$$

$H(u)$ is the Butterworth low-pass filter and $F(u)$ is Fourier transformation of image. $F'(u)$ is the result of low-pass Fourier transformation.

2）Finite impulse response (FIR) filter
A FIR filter is constructed at first and then use it to remove the strip noise. The non-recursive algorithms such as window function, frequency sampling and constrained least squares are usually used to construct FIR filter. The FIR method can keep the integrality of image information and minimize the distortion of spectral information.

3）Wavelet transform
Wavelet transform decomposes image to high frequency image and low frequency image using wavelet decomposition. A threshold is set and the wavelet coefficients along the strip direction that is less than the threshold are set to zero. Then the stripe removed image is generated after performing a wavelet reconstruction. Wavelet transform method has the advantage that it can describe different frequency component of signal and keep more details information of image than low-pass filter.

3. Relative Radiometric Correction Experiment and Accuracy Assessment

3.1 Images Selection

Two of Beijing-1 small satellite multi-spectral and panchromatic raw images with vertical stripe noise are selected to do relative radiometric correction experiment as shown in Figure 1. And the information of these two experiment image are listed in Table 1.

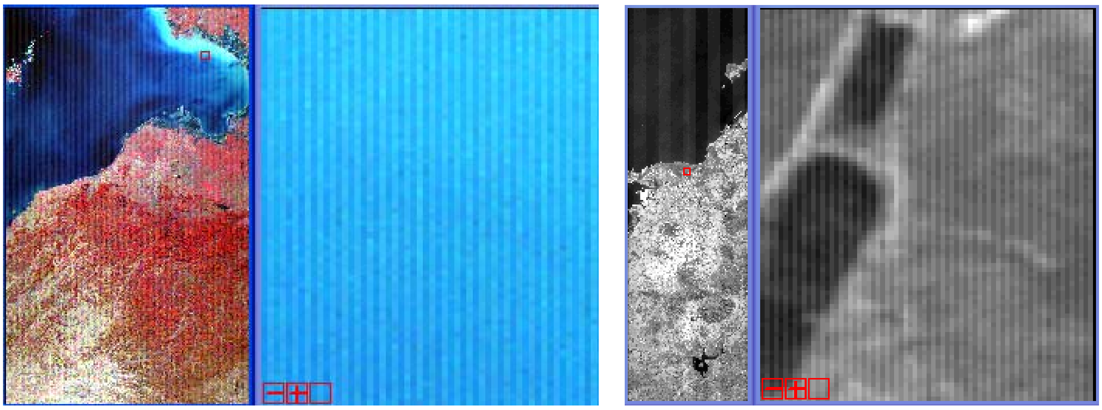

Figure 1. Beijing-1 small satellite multi-spectral and panchromatic raw images

Table 1. The information of two experiment images

Data	Acquisition Time	Line	Column	Bit
MSI	2008-10-10	16250	9984	8bit
PAN	2008-05-28	20000	6056	8bit

3.2 Method of Precision Assessment

DN difference of neighbor column, generalized noise and stripe ratio methods are used to assess the precision of relative radiometric correction. By calculating the absolute mean value of the difference between neighbor columns of radiometric corrected image, the DN difference of neighbor column method is to assess the gray value difference between neighbor columns. The calculation equation of DN difference of neighbor column is shown below.

$$MD = \frac{1}{N-1}\sum_{J=1}^{N-1}\left|\frac{1}{M}\sum_{i=1}^{M}DN_{i,j} - \frac{1}{M}\sum_{i=1}^{M}DN_{i,j+1}\right| \quad (5)$$

Where, MD is the mean DN difference, DN is the pixel gray value, M is the height and N is the width of image. A M×N homogeneous area in the relative radiometric corrected image is selected when using the generalized noise method. The absolute mean value of difference between column mean and local area image DN mean (Err) is calculated and the ratio of Err and the local area image DN mean is the generalized noise (RE). The equations are following:

$$Err = \frac{1}{N}\sum_{J=1}^{N}\left|\frac{1}{M}\sum_{i=1}^{M}DN_{i,j} - \overline{DN}\right| \qquad RE = Err/\overline{DN} \quad (6)$$

$\overline{DN}$ is the mean value of local area image. M is the height and N is the width of sub-cut image. Stripe ratio method aims to quantitatively measure the removal result of periodic noise in frequency domain based on Fourier transform. In the first time, the mean value of Fourier transform on horizontal direction and vertical direction at the Nyquist frequency and its ratio are calculated. This ratio value is named as strip amount (S) which is calculated according to equation (7).

$$S = \frac{\overline{\left|F(u)_{Nyquist}\right|}}{\overline{\left|F(v)_{Nyquist}\right|}} \tag{7}$$

$F(u)_{Nyquist}$ is the Fourier transform on horizontal direction at the Nyquist frequency and $F(v)_{Nyquist}$ is the Fourier transform on vertical direction at the Nyquist frequency. For an ideal image, the different of Nyquist components of Fourier transformations in the horizontal and vertical direction should be small. In other words, the S should be close to one when the vertical stripes are removed completely. The more stripes exist in the image, the larger S is calculated. So in the second time, we use the strip removal ratio (SR) between the strip amount of raw image (S_{Before}) and the destriped image (S_{After}) to determine whether the vertical stripe removed completely or not.

$$SR = \frac{S_{Before} - S_{After}}{S_{Before}} \times 100\% \tag{8}$$

3.3 Precision Assessment

In the paper, the seven relative radiometric correction methods of radiometric coefficient, histogram equalization, histogram matching, neighbor column equalization, Fourier transform, finite impulse response filter and wavelet transform are used to radiometric correct Beijing-1 small satellite multi-spectral and raw image shown in figure 1. And the part of relative radiometric corrected image examples are display in Figure 2 to 5.

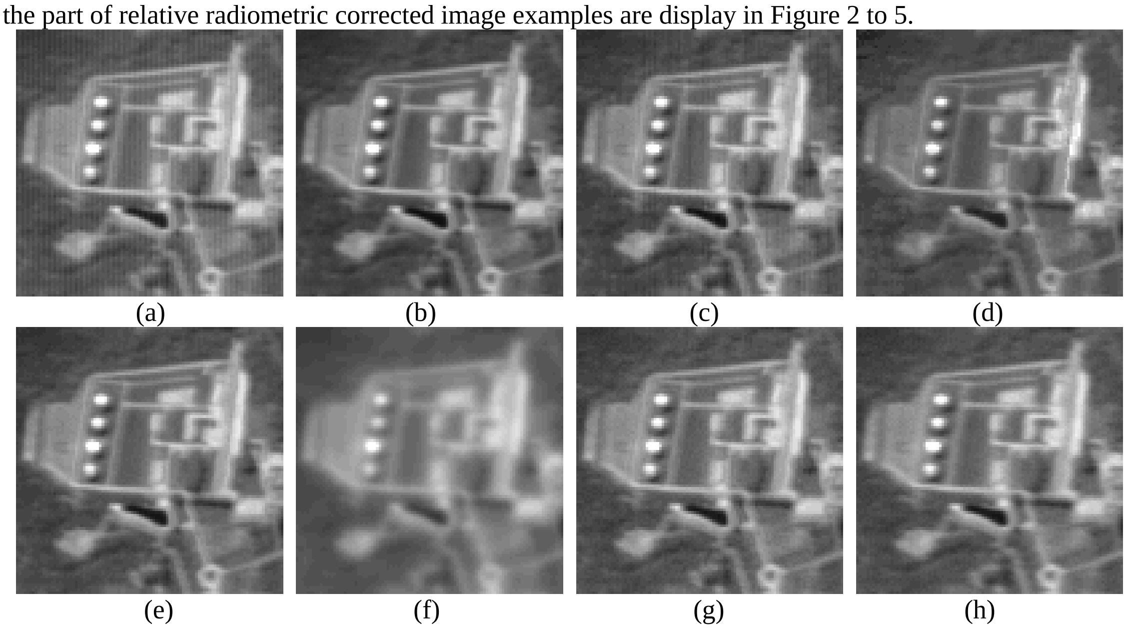

Figure 2. Part of panchromatic band relative radiometric corrected image

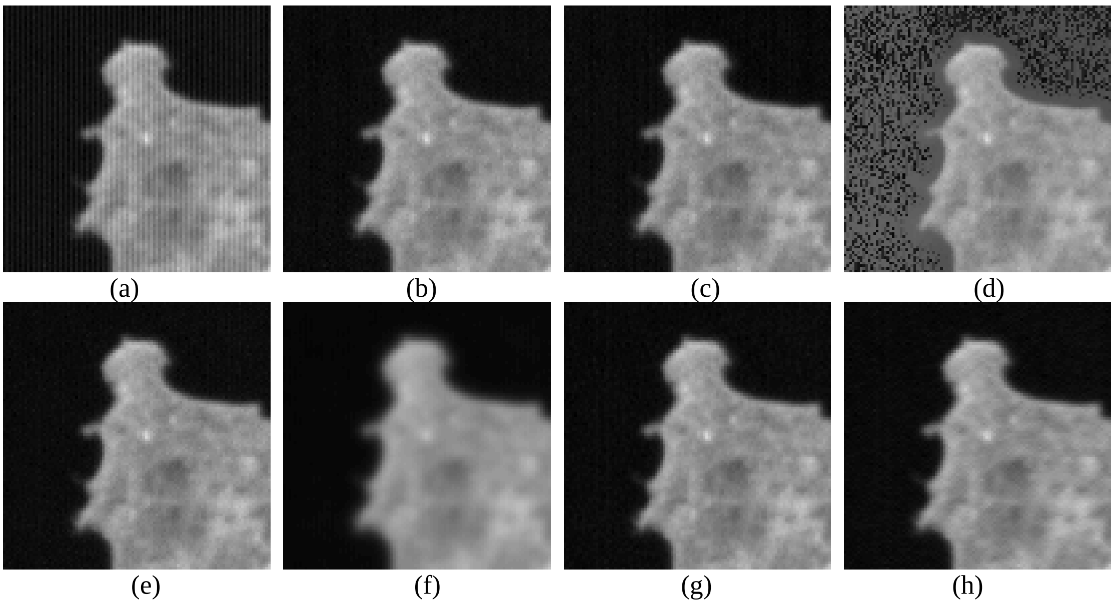

Figure 3. Part of NIR band relative radiometric corrected image

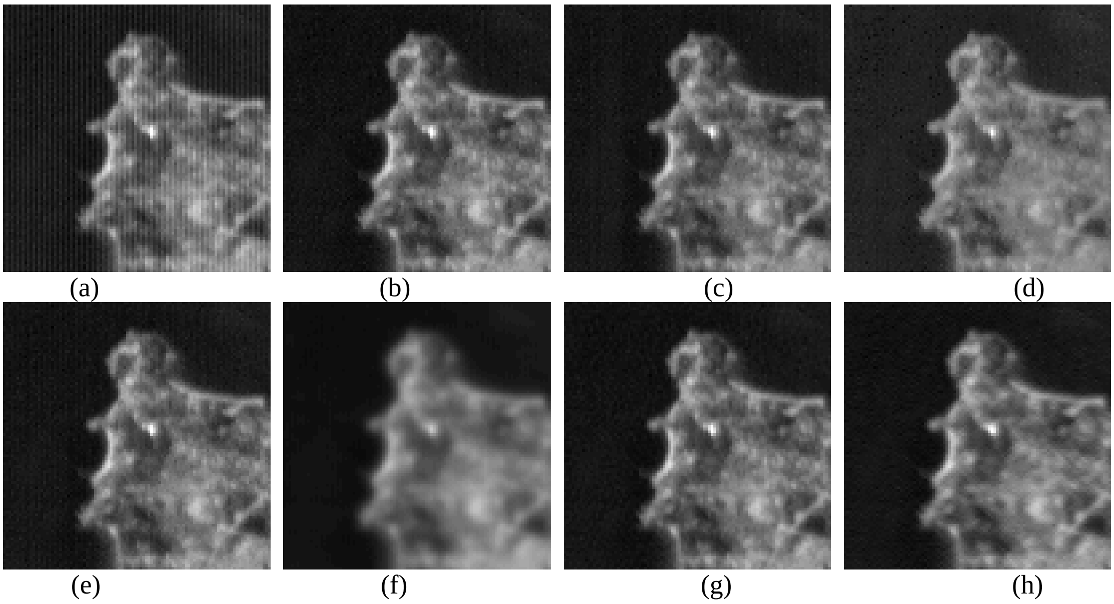

Figure 4. Part of RED band relative radiometric corrected image

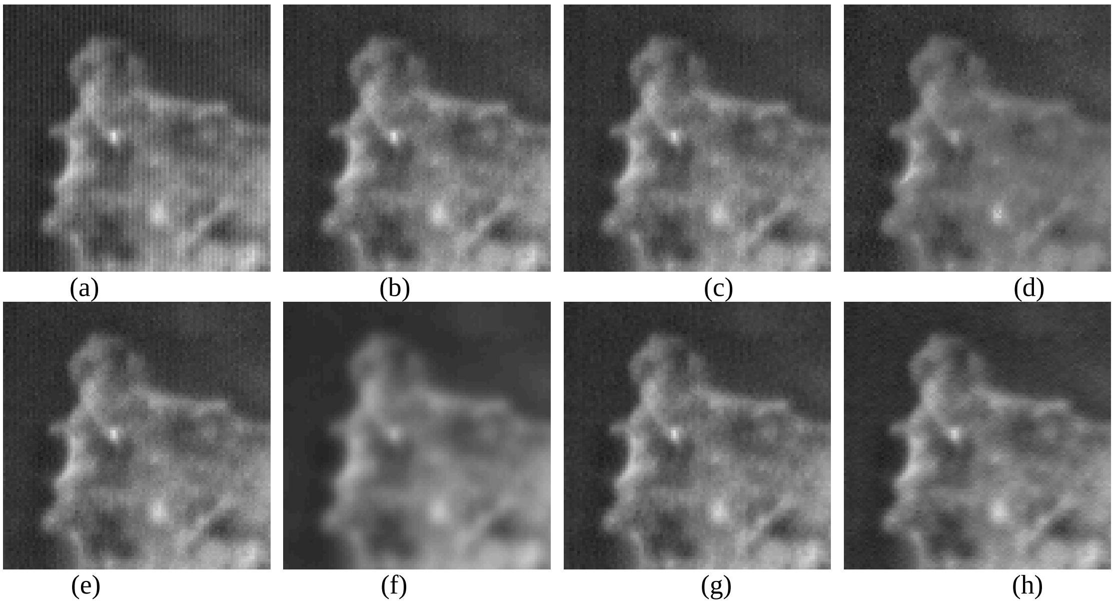

Figure 5. Part of GREEN band relative radiometric corrected image
(a)raw image, (b)Coefficient, (c)Histogram equalization, (d)Histogram matching,
(e)Neighbor column equalization, (f)Fourier transform, (g)Finite impulse response filter, (h)Wavelet transform

In addition, the quality assessment factors of DN difference of neighbor column (DM), generalized noise (RE) and strip removal ratio (SR) are used to quantitative assess the precision of the different method of relative radiometric correction which are listed in the Table 2.

Table 2. The quantitative assessment of relative radiometric corrected image

Quality Factors / Methods	panchromatic image			NIR band image		
	MD	RE (%)	SR (%)	MD	RE (%)	SR (%)
Radiometric Coefficient	0. 30	1. 88	95. 77	0. 31	2. 48	93. 50
Histogram equalization	0. 35	1. 45	93. 38	0. 32	2. 02	95. 83
Histogram matching	0. 13	1. 17	94. 93	0. 57	5. 76	98. 30
Neighbor column equalization	0. 29	0. 63	78. 31	0. 25	1. 57	91. 55
Fourier transform	0. 13	0. 68	68. 32	0. 26	1. 36	73. 67
Finite impulse response filter	0. 16	0. 72	82. 96	0. 25	1. 34	97. 53

Wavelet transform	0.12	0.60	89.33	0.12	1.32	98.57

Methods \ Quality Factors	RED band image			GREEN band image		
	MD	RE (%)	SR (%)	MD	RE (%)	SR (%)
Radiometric Coefficient	0.28	3.15	88.58	0.33	2.10	84.55
Histogram equalization	0.29	1.55	93.81	0.40	2.07	96.62
Histogram matching	0.10	3.14	97.25	0.09	2.77	96.39
Neighbor column equalization	0.52	1.73	84.36	0.49	1.82	85.94
Fourier transform	0.20	1.30	77.81	0.13	1.77	76.88
Finite impulse response filter	0.21	1.37	96.85	0.26	1.79	96.61
Wavelet transform	0.11	1.30	98.40	0.11	1.78	97.40

According to the results of subjective and objective assessment, the radiometric coefficient method is better than the other six methods for its small MD and RE and big SR and the higher of information fidelity between the raw and corrected image. In the statistical methods, the effect of histogram equalization is correlation with the uniformity of scene and can be found the stripe in the corrected image and certainly changes the DN distribution of raw image during destriping. Histogram matching method is closely correlation with the distribution of artifacts in scene image and not suitable for the image which has saturation pixel. Neighbor column equalization is the best method among the statistical methods and the information of raw image is withheld maximum. Fourier and wavelet transform will blur the image. And the effect of finite impulse response filter is the best among the filter methods which not only can remove the vertical stripe but also obtain the edge sharp information.

4. Conclusion

According to the result of relative radiometric correction precision assessment, it is suggested that the radiometric coefficient, neighbor column equalization and finite impulse response filter methods are suitable for radiometric correction and could be used in the space optical linear CCD remote sensing data preprocessing priority. By the way, this work is supported by The National Key Technology R&D Program 2011BAH23B02.

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