THE EFFICIENT METHOD TO DETECT DEFECTIVE DETECTOR OF THE SWIR BAND OF SPOT 4

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ABSTRACT:

This paper presents the efficient method to detect the defective detectors of the SWIR band of SPOT 4. The key of this method are to flatten the baseline of the data using high pass band filter instead of differentiation. This method is made up six steps. First step is to apply image enhancement techniques to enhance the lines imaged by defective detector and improve the quality of an image. Second step is processed by summing the enhanced image in line direction. These summed data have the peaks that represent the defective detectors and the curved baseline characterized by the reflectivity of Earth surface. In order to exactly detect these peaks, third step is to flatten the curved baseline using high pass filtering in the frequency domain. In fourth step, the data with flat baseline is normalized to have zero mean and unity standard deviation. In fifth step, the defective detectors are detected using 99.9% confidence interval. Finally, after removing the detected ones in summed data, the steps from third to five are iterated. Three SPOT 4 images, which have different reflectivity of Earth surface and different sensor, were used to validate this method. The overall accuracy of detection for three images was 97.9%. This result shows that this method can detect efficiently the lines made by defective detectors.

KEY WORDS: defective detector, SWIR, SPOT 4, high pass filter

1. INTRODUCTION

On February 1986, SPOT 1 satellite was launched and has collected imagery with a spatial resolution of 10m in panchromatic mode and 20m in multi-spectral mode. Also, SPOT 2 joined SPOT 1 in orbit on January 1990, followed by SPOT 3 on September 1993. On March 1998 the SPOT 4 satellite was launched, and its performance has been increased by adding a new short wave infrared spectral band (SWIR), extending its nominal lifetime from three to five years and improving operational possibilities.

In the field of environment and agriculture, the sensitivity of the short wave infrared band of SPOT4 to variations in canopy or soil water content has the effect of creating a strong contrast between soil and vegetation reflectance; it will thus be easier to identify variations in the canopy structure, especially when these are not very great. The interest of the SWIR is significant for the discrimination of wet areas, the identification of water stress in plants, the classification of some crops and vegetation areas, and detection of forest fire (Fraser et. al., 2000; Lim et. al., 2000; Xiao et. al., 2002).

However, the SWIR detectors on SPOT4 are much more sensitive to the space environment, so that the number of defective detectors, which is "out of order" detectors, in SWIR band is increasing, and now reaches more than 3 percents. In order to properly use the images of SWIR band, it is important to automatically detect the presence of defective detectors and to restore the radiometry impacted by defective detectors.

Until the present day, the detection of defective detectors has been performed by using the differentiation of data (SPOT, 1998). This method is processed by three steps, which include statistics computations (average and standard deviation) over blocks of SWIR image, estimation of defective detectors by differentiation of image blocks, and filtering of the results and updating of the defective detectors. However, it is very difficult that defective detectors are detected using the differentiation of image blocks, because defective detectors can exist successively. And then, it is possible to not detect "out of order" detectors and to detect detectors that are not out of order.

This paper proposes the efficient method of detecting the defective detectors without differentiation. The defective detectors make the peaks in the data processed by summing the image in line direction, because the values of the pixels imaged by them are much different from those of the adjacent pixels. The peak can not be easily found due to the difference of baseline characterized by the reflectivity of Earth surface. The key of this method are to flatten the curved baseline, which means baseline level characterized by the reflectivity of Earth surface, using high pass band filtering in frequency domain.

The remainder of the paper is organized as follows. Section 2 presents the method to detect "out of order" detectors. In Section 3, three SPOT 4 images used to testify this method are explained. Section 4 presents the experimental results for this method. Finally, a discussion and conclusion of various aspects of this method is provided in Section 5.

2. METHODOLOGY

The detectors on optic sensor of satellite are sensitive to the space environment, so that some of them may do not work. We call them the defective detectors. These defective detectors make the stripes on a pushbroom image. These stripes must be detected and corrected to rightly use the image.

In this paper, the efficient method to detect the defective detectors is presented. This method is made up six steps. First step is to apply image enhancement techniques to enhance the stripes and improve the quality of an image. Second step is to sum the enhanced image in line direction, and third step is to flatten the curved baseline using high pass filtering in the frequency domain. In fourth and five steps, the data with flat baseline is normalized and the defective detectors are detected using a proper confidence interval. Finally, after removing the detected ones, the steps from third to five are iterated.

2.1 Image Enhancement

In order to enhance the stripes of an image and improve the quality of an image, the histogram stretching method is applied. This method is defined as follow.

$$BV_c(n,m) = \frac{255}{Nc_2 - Nc_1}\left[BV(n,m) - Nc_1\right] \quad (1)$$

where (n,m) = (line, pixel)

$BV(n,m)$ = brightness value in (n, m)

$BV_c(n,m)$ = the enhanced brightness value

Nc_1 = minimum brightness value of an image

Nc_2 = maximum brightness value of an image

2.2 Summing Image in Line Direction

The same pixel of each line is obtained by same detector, because a pushbroom image is collected sequentially line by line. The enhanced image is summed in line direction as follow.

$$S(m) = \sum_{n=0}^{N-1} BV_c(n,m) \quad (2)$$

where $S(m)$ = data summed in line direction

N = the size of the line

2.3 Flattening Baseline Using High Pass Filter

The summed data has curved baseline characterized by the reflectivity of Earth surface and the peaks that are occurred by "out of order" detectors. The values of these peaks have more or less than those of baseline, which are decided by the trend of adjacent data. Therefore, in order to find the peaks using the same statistical approach for all of data, they must have an equal baseline. The method of flattening the baseline is generally to differentiate the summed data. However, it is very difficult that the peaks of the defective detectors are detected from the differentiating data, because if they exist successively they can not be easily identified. In order to solve this problem, high pass filtering is applied. The disadvantage of this method is not easily to flatten the baseline compared with differentiation of data. However, this method has the great advantage easily and exactly to find the peaks using the statistical approach. The summed data of equation (2) can be expressed by Fourier series as follow (Oppenheim et. al., 1996).

$$S(m) = \sum_{k=0}^{M-1} a_k e^{jk(2\pi/M)m} \quad (3)$$

where a_k = Fourier coefficients

M = the size of the pixel

The baseline of the summed data can be supposed to have Fourier coefficients of low frequency, because the baseline is characterized by the reflectivity of Earth surface that have smooth surface, so that if the Fourier coefficients of baseline are removed, the summed data can be flattened. The flattened data, S_B is defined as

$$S_B(m) = \sum_{k=m_c}^{M-m_c-1} a_k e^{jk(2\pi/M)m} \quad (4)$$

where m_c = cut-off frequency.

This procedure is practically processed using Fast Fourier Transform (FFT).

2.4 Data Normalization

It can be supposed that the data flattened using high pass filter has a normal distribution, so that they are normalized with zero mean and unity standard deviation as follow.

$$Z(m) = \frac{S_B(m) - \mu_s}{\sigma_s} \quad (5)$$

where $Z(m)$ = normalized data

μ_s = mean of $S_B(m)$

σ_s = standard deviation of $S_B(m)$

2.5 Detection of the Defective Detectors

The defective detectors can be detected using a proper confidence interval from this normalized data. This proper confidence level must be determined by the experiment. The defective detectors can be detected using the following equation.

$$V_d = \begin{cases} 0, & others \\ 1, & |Z(m)| \le c \end{cases} \quad (6)$$

where c = the z-value of confidence interval.

If the detector is out of order, V_d will be one, and if not V_d will be zero.

2.6 Iterations

When the summed data are flattened using high pass filtering and the defective detectors are detected using the confidence interval, the peaks in the data largely affect the result. In order to remove these affections, the peaks that are considered as the defective detectors in fifth step were removed from the summed data of second step, and the defective detectors are redetected.

3. DATASET

In order to validate this method, we used three SPOT 4 images. Two of three were imaged by HRVIR1 sensor on 27 February 2004. They also had the same orbit, but the different reflectivity of Earth surface: One only had land, another had land and sea. The third was imaged by HRVIR2 sensor on 11 February 2004, and had the a few cloud. All of images had the defective detectors. Figure 1 shows three SWIR images of SPOT 4.

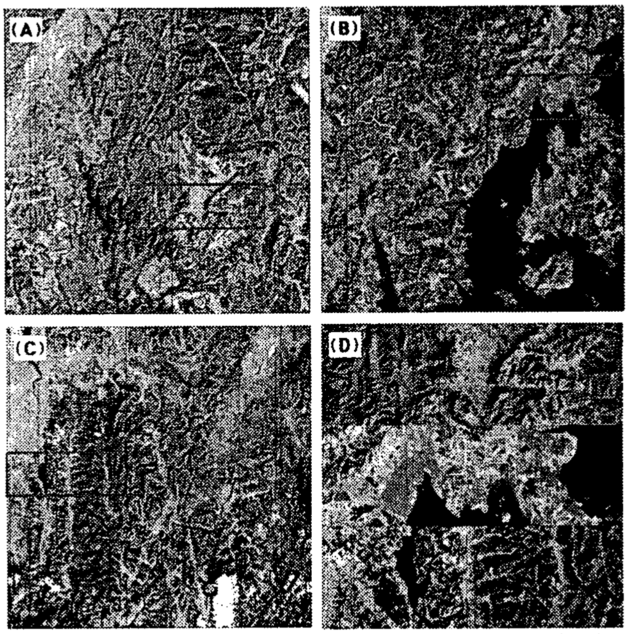

Figure 1. Three SWIR images of SPOT 4. (A) and (B) were imaged by HRVIR1 sensor on 27 February 2004, and (C) was HRVIR2 sensor on 11 February 2004. (D) shows clipped image with the boxes of (A), (B), and (C)

4. EXPERIMENT AND RESULT

In order to test the performance of method that detects the defective detectors using high pass filter, three SPOT 4 images were used. Firstly, each image was enhanced by histogram stretching method, and then summed in line direction. Figure 2 represents the data summed in line direction. As shown in Figure 2, the summed data had the curved baseline and many peaks. Figure 2(A) was relatively flat, because the image had the land. Figure 2(A) and 2(B) had the same defective detectors because they had the same sensor and orbit. Figure 2(C) shows the summed data of HRVIR2 sensor. This summed data had more peaks than those of Figure 2(A) and 2(B), because HRVIR2 sensor has more defective detectors than HRVIR1.

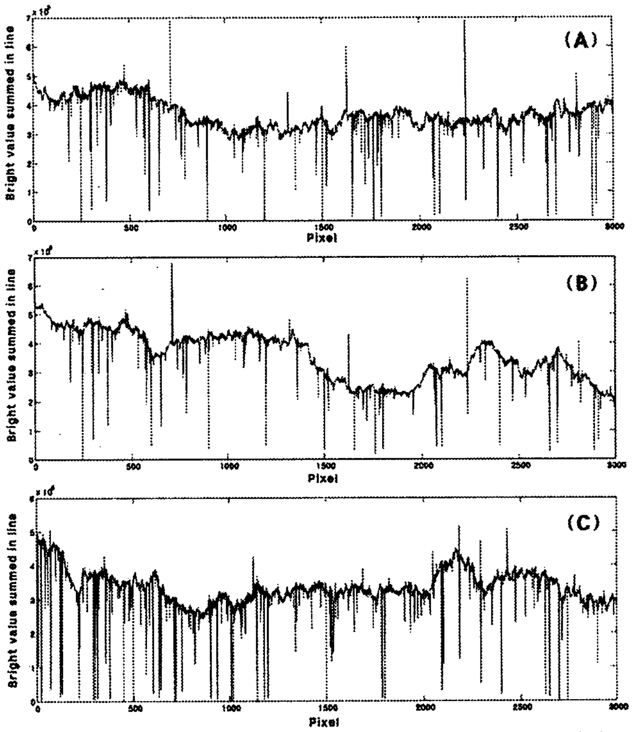

Figure 2. The summed data of three SWIR images. (A), (B), and (C) come from (A), (B) and (C) of Figure 1.

Most simple way is to suppose that the summed data are the random variable with the normal distribution, and then to detect the defective detectors directly using the confidence level after the summed data are normalized. However, the peaks are not decided by the mean of all data, but by the mean of adjacent data, so that all of the peaks have different bases. These different bases produce the curved baseline in the data. This baseline must be flattened before the data normalization process. In this paper, the high pass filtering was used to flatten the curved baseline. The summed data was transformed into frequency domain by FFT, and the low frequencies considered as the affection of the baseline were removed, and the processed data was inversely transformed into space domain by IFFT. The flat baseline was finally made by this procedure. Figure 3 compares the baselines that are generated by high pass filtering when the cut-off frequencies are 0.001, 0.003, and 0.012 (1/m). The generated baseline of Figure 3(A) was not satisfied with a curve of original baseline, and that of Figure 3(C) was distorted by the affection of the peaks. If 0.012 of Figure 3(C) are used as the cut-off frequency, the adjacent data of the peak can be considered as the defective detectors. The generated baseline of Figure 3(B) was relatively good with respect to those of Figure 3(A) and (C).

Therefore, the best cut-off frequency was decided as 3.0×10^{-3} (1/m). All of the summed data was flattened with the cut-off frequency of 3.0×10^{-3} (1/m).

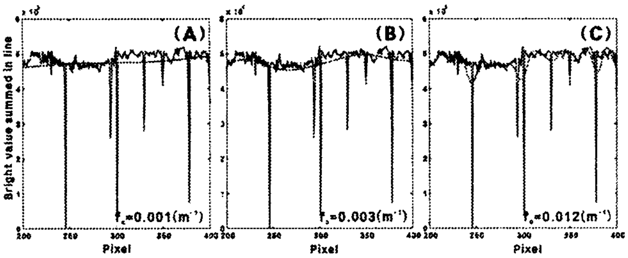

Figure 3. The comparison of the baselines that are generated by high pass filtering when the cut-off frequencies are (A) 0.001, (B) 0.003, and (C) 0.012(1/m).

The summed data was normalized. The z-value of confidence interval was decided by other bands of SPOT 4. The flattened data of other bands had nearly the value between -3.8 and 3.8, so that the z-value of confidence interval was decided as 3.8. The defective detectors were finally detected using Equation (6).

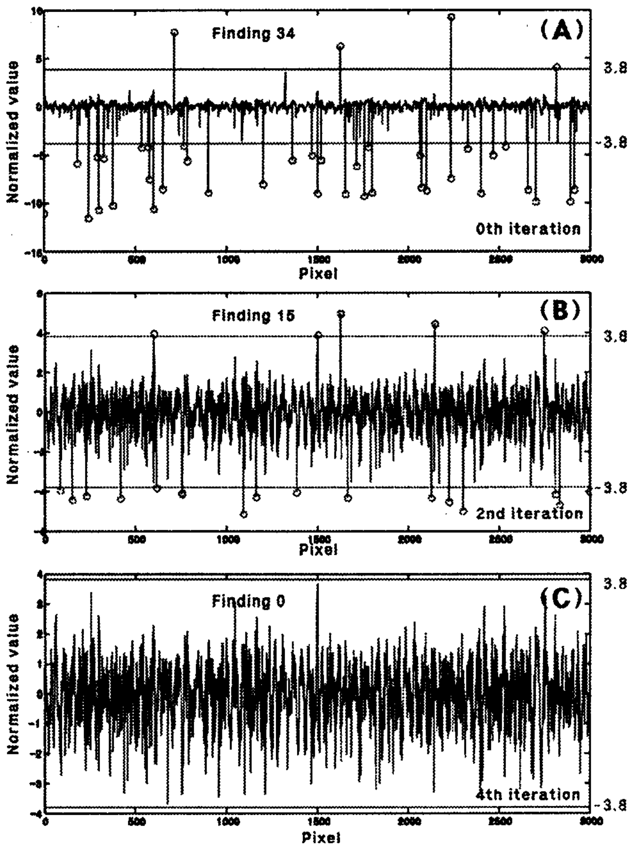

Figure 4. The results from detecting the defective detectors from SWIR image of Figure 1(A). (A), (B), and (C) respectively show 0^{th}, 2^{nd}, and 4^{th} iteration.

These detected defective detectors largely affected mean and standard deviation of data during data normalization, so that were removed from the summed data, and then high pass filtering, data normalization and the detection of defective detectors was reprocessed. These iterations were performed until the defective detectors are not detected. Figure 4 shows the results obtained by detecting the defective detectors for SWIR image of Figure 1(A), and Table 1 shows the result of detection for three SWIR images. All of defective detectors except one were detected in the image A and C, but the number of misdetection was relatively large: 6 and 5 in image A and C. Otherwise, four defective detectors were not found in the image B because of low brightness value in the sea. The defective detectors that are not detected also were slightly out of order. The overall accuracy of three images was 97.9% (277/283).

Table 1. The result of detection about three SWIR image

ID	A	B	C
Sensor	HRVIR1	HRVIR1	HRVIR2
Surface Type	Land	Land and Sea	Land and Cloud
No. of Iteration	3	3	3
Defective detectors	87	87	109
No. of detection	86 (98.9%)	83 (95.4%)	108 (99.1%)
No. of Misdetection	6	1	5

5. CONCLUSION

In order to provide end user the SWIR image of good quality, the defective detectors must be detected and corrected. In this paper, we proposed how to detect the defective detectors using high pass filter. Three SPOT4 SWIR image were used to validate this method. The defective detectors were detected during three iterations. The accuracies of detection in all images were more than 95%, and the overall accuracy of these three images was 97.9% (277/283).

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