Current Trends in Technology and Science
ISSN : 2279-0535
8thSASTech 2014 Symposium on Advances in Science & Technology-Commission-IV Mashhad, Iran

Detection and Elimination of Striped Noise in CHRIS-PROBA Sensor Images

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Abstract — CHRIS is a multi band sensor placed on PROBA -1 platform and is imaging the earth on a Push-Broom method since 2001. After 13 years of operation due to many reasons such as solar radiation, effect of earth magnetic field, temperature variation, some errors in electronic functioning of detectors happened and their response functions changed as a result. These changes are appeared as vertical and horizontal dark or pale stripes in different bands and locations in the images. In this work after an introduction of sensor operation method, different methods of vertical/horizontal noise detection and a method of noise removal are introduced and implemented on noisy images. This method benefits from advantage of de-striping images while maintaining radiometric information.

Keyword — CHRIS Sensor, De-Striping, Electronic Effect, Noise.

1. Introduction

The CHRIS sensor was launched to space on PROBA-1 satellite in 2001 and it is imaging earth since that time. It works in 5 different modes, depending on kind of use employs various spatial and spectralresolutions. This sensor that images on a Push-Broom method is designed in a way that 5 images of every spot is taken with angles of +55,+36,0,-36 and -55. Then combine them to produce final image. Collection time for a frame is 12.7 ms.Thissensor is designed in a way that received light from the surface of the earth is guided, centralized and passed from a small aperture after entering telescope. It will be dispersed in different spectrums and registered on detectors of sensor using a prism. Some CCDs are allocated for error correction in each row [1].

The satellite is designed in such a way that some corrections are made on In-flight mode. These corrections are in terms of: Flat-Field Calibration which is done owing the help of sun and calibration ground stations monthly. Wavelengths correction is done monthly with the help of oxygen absorption line in 760 nm band and the latest correction is DC offset calibration which is implemented using dark reference pixel and smear pixel by CCD arrays in each satellite rotation [2]. Table 1 and Table 2 demonstrate configuration of operating modes and sensor general features respectively [3].

Cancelling non-periodic strip noise appear in different bands and locations is the main purpose of this work. It is less complicated to correct vertical noises since one row is not lost entirely. Histogram modification and filtering procedure are used for vertical noise modification. Compared to previous algorithms, the advantage of this method beside correction is maintaining radiometric information .In next part after introducing the reason of noise creation, recognition and elimination of vertical /horizontal noise are introduced and after that by comparing the radiometric information of images before and after de-striping, quantitative evaluation of proposed algorithm will be discussed.

Table (1).Operation modes and configuration in CHRIS sensor [3]

Operating mode	No of bands	GSD(m)	Swath width	Application
1	62	34	Full	Aerosols
2	18	18	Full	Water
3	18	18	Full	Land
4	18	18	Full	Chlorophyll
5	37	18	Half	Land

Table (2).General features of CHRIS sensor [3]

Instrument	Push-Broom imaging spectrometer
Field of view	1.3°
Ground swath	13.5 km
Altitude	Apogee:688 km.perigee:556 km
Orbit inclination	97.8°
Descending node	12:10 local time
Across track pixel size	18m or 36m
Along track pixel size	Finest resolution is 18m
Number of images	5 acquisition of the same area at +55,+36,0,-36,-55 view angles duringthe same orbit
Spectral range	410nm to 1050nm
Spectral resolution	From 1.25nm @ 400nm to 11nm @ 1050nm and binning possibility

Number of spectral bands	From 18 bands at a spatial resolution of 18m to 63 at 36m
Sensor type	E2V CCD25-20(1152x780 pixels.25µm x 25µm pixel size, full frame transfer. thinned and back-illuminated)
Digitalization	12 bit
Signal to noise ratio	Max 250 @ target albedo=0.2, λ=800nm,gain=8.538

2. Methodology

2.1. Detection and Elimination of Striped Noise in CHRIS-PROBA Sensor Images

The most important reason for appearance of striped noise and losing information in images is error in CCD operating and electronic noise in sensor due to different reasons. After 13 years of operation, response function of some CCDs has lost their calibration partly due to solar radiation effect [4]. Temperature variation also makes some changes in the width of light aperture causes error and as far as temperature goes up the size of light aperture increases and increases the error as well [5], [6]. Shot noise, Dark noise (Dark current), Read noise, Round-off error and Smearing effect are some examples of electronic noises of sensor. Temperature and non-identical CCDs employed in sensor are the most important factors for creating electronic noises [3]. In this section first the horizontal noise is introduced, also its features, recognition methods and their elimination is discussed. Vertical noise cancellation and de-stripping images with histogram modification and filtering are introduced subsequently. At the end, mentioned algorithms are implemented on noisy images and compared with the reference images.

In horizontal noise that randomly occurs in different bands and locations, only even pixels are lost. This can be modified using averaging filter with 3x3 moving window with the lost pixel in the center (pixels with zero value). This noise occurs more in the edges of the images (upper and lower edges) or sometime the rows close to the edges. For the same reason edges are starting point for recognition of noise location (Fig.1). Modification method uses averaging of adjacent pixels for the lost pixel (Fig. 2) [7], [8], [9].

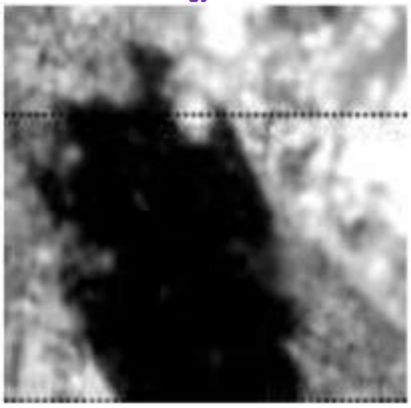

Fig 1:Horizontal noise in CHRIS sensor images

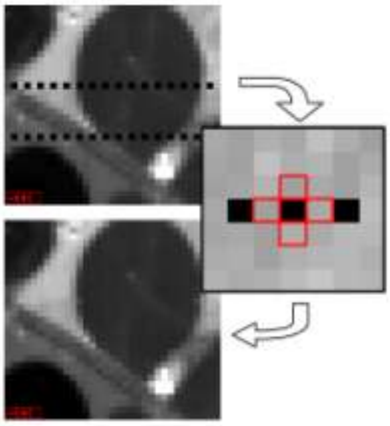

Fig 2: Modified horizontal noise algorithm in CHRIS sensor images

For the vertical noise in CHRIS sensor images, noise occurs randomly in different bands and locations and creates dark or pale vertical strip in some parts of images. Histogram modification is one way for denoising. In order to achieve mentioned modification, it is presumed that all detectors are similar in statistic distribution and they are identical in all aspects. On the other hand a homogeneous environment is required for testing this algorithm. Under this assumption it is possible to decrease the vertical stripped with a match between sub-image histogram of each detector with the histogram of whole images using equation (1) [10], [11].

$$X_{n,k} = G_{n,k} \cdot \gamma_{b,k} \cdot g_{b,k} \cdot L + C_{n,k} \quad (1)$$

here b is a detector that does registering in column n and band k, L is signal radiance, $G_{n,k}$ is the gain associated to the detector n for band k,$\gamma_{b,k}$ is the inter register gain,$g_{n,k}$ is the inter detector gain and $C_{n,k}$ is the bias associated with the detector [8]. Using Eq.1 the output of each column is achievable. Correction factor will be calculated after estimation of gain and bias, also it will be applied for all noisy columns. Generally gain and bias will be extracted from those images acquired at night (dark images) or images taken from homogeneous environments like ice covered surfaces, seas or deserts. It's an important point that correctional factor calculated for a round cannot compensate the noise in acquired images in other rounds satisfactorily, that is the reason why gain and bias should be calculated directly out of statistics distribution. If we consider the inter register gain and inter detector gain equal, then we will be able to do a second calibration for each column according to Eq.2. L is radiance in each pixel in column n in band k [8].

$$Y_{n,k} = G_{n,k} \cdot L + C_{n,k} \quad (2)$$

$Y_{n,k}$is modified pixel. $C_{n,k}$and $G_{n,k}$are gain and bias coefficient respectively. Eqs.3~4used for comparing statistical configuration of modifying column with statistical configuration of entire system. In these equations $\overline{m}_k$ and $\overline{s}_k$ are the mean and standard deviation of whole image respectively. Also$m_{n,k}$ and $s_{n,k}$ are mean and standard deviation of modifying column respectively.

$$G_{n,k} = \frac{\overline{s}_k}{s_{n,k}} \quad (3)$$

$$C_{n,k} = \overline{m}_k - G_{n,k} \cdot m_{n,k} \quad (4)$$

Despite simple apply and good results of this methodology, in many cases it has also some disadvantages as mentioned below [8].

- The algorithm is strongly image dependent and the sub-image statistics cannot be matched with the statistics of whole image concurrently.
- Wide areas characterized by different surfaces (snow, cloud, very dense urban quarters) could be considered as sources of error during correction phase
- Radiometric information could be affected by the correction in some cases.

Due to the problems mentioned in last item, a new algorithm is needed to solve this problem. The second method is vertical noise correction in images using filters in spatial domain. In this method stripping of images is considered as a multiplier factor of columns for images that makes strong variations in pixels of adjacent columns. These variations are shown in frequency domain calculating high frequency components in image power spectrum. Components are higher than average of columns which could be decreased using a low pass filter.

In this algorithm first the average radiance of each column is calculated then the logarithm of average will be calculated. In the next step a low pass filter will be applied to cut high frequency components. Finally the results of this step are subtracted from the logarithm of average and after calculating anti logarithm. Correction factors will be obtained and will be applied to each column of image [5], [6], [9].

However, it would be more efficient if a Butterworth filter with configuration set ability (amplitude and cut off) is used instead of a low pass filter [12]. Of course, this algorithm doesn't work well in very heterogeneous areas like shadows and clouds. After applying this method, dark strips remains. In order to solve this problem some changes are needed to be applied to the previous algorithm in order to exclude pixels of high heterogeneous areas in averaging of each column. In order to do these, the following steps should be carried out after calculating radiance level in every column of each band.

Standard deviation of entire columns is calculated in each band. Standard deviation is applied to define a new area of values which doesn't include bright pixels and finally in this new area of values, the average of each column is calculated [8]. In other words this definition of new area for values makes it possible that the average of columns be less affected of pixels of image which are statistically different with other parts. The span of this area in input is definable in standard deviation and we can reach to desired result with changing and modifying repeatedly.

2.2. De-Striped Algorithm Applying on CHRIS Sensor Images

Figs. 3~4 make a comparison between image before and after applying the de-striped algorithm. Fig. 3 is a part of Lebanon desert in band 1 and Fig. 4 is from Tor Vergata university campus in Rome.

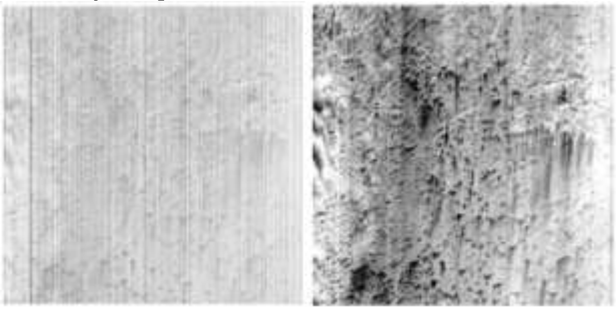

Fig 3: Lebanon desert image in band 1 before de-striping (left) and after de-striping (right)

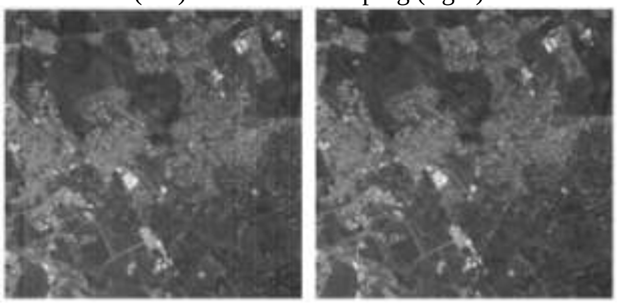

Fig 4: Tor Vergata university campus in band 1before de-striping (left) and after de-striping (right)

As it's shown in Fig. 5 striped noise will not be corrected completely for columns covered by shadows and clouds. However covering bright pixels will improve the results and none of stripe will remain after correction.

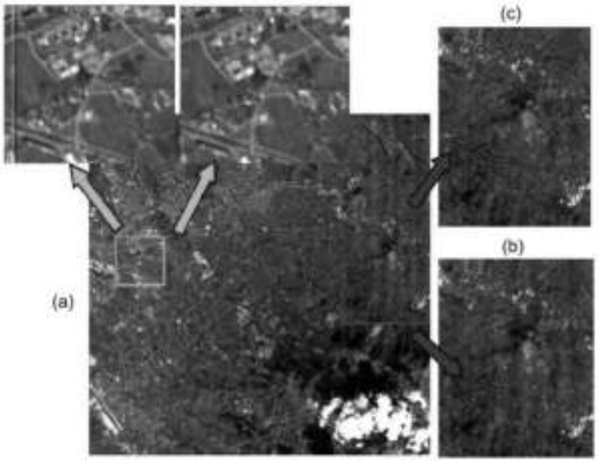

Fig 5: (a) Original image taken by CHRIS sensor (b) Area affected by residual stripes close to a columns of clouds (c) The same area mitigated by the use of bright pixel masking

Fig. 6 illustrates some columns of image making dark stripes. All information of that column is lost and pixels in different levels along the on track direction are to be corrected. This algorithm is suitable for islands, ports, coastal areas and large areas covered by sea. Tuning of parameters related to modification (filtering parameters and ranges for mean extraction) can cause reducing noise of image but some of blurred stripes will be remained eventually. However the result is not satisfactory for all kinds of images [8].

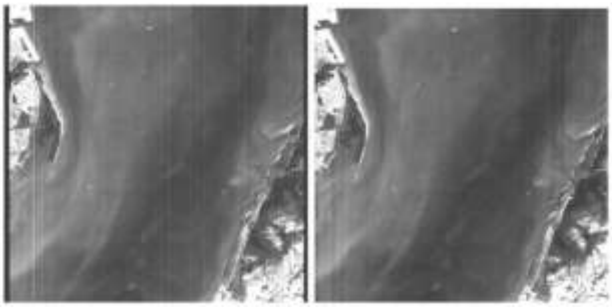
Fig 6: Lost column modification algorithm for coastal areas, original image (left) and after modification (right)

3. Analysis and Results

One of the most important terms that should be considered during modification of noisy images is to not losing or distorting radiometric information. As it is shown in table 3 for all bands modified algorithm, despite having little impact on radiometric information in images, it doesn’t impose the related changes to statistical information.

Table (3). Comparison between statistics of Tor Vergata university campus before and after de-striping

Band	Mean original	standard deviation original	Mean de-striped	standard deviation de-striped
Band 1	51.264	5.519	51.247	5.336
Band 2	41.747	6.874	41.740	6.727
Band 3	36.042	6.892	36.031	6.765
Band 4	35.928	7.411	35.920	7.282
Band 5	31.025	7.025	31.020	6.912
Band 6	25.796	7.368	25.794	7.278
Band 7	24.825	7.851	24.842	7.758
Band 8	24.707	8.182	24.706	8.090
Band 9	26.878	7.027	26.879	6.940
Band 10	31.249	7.437	31.247	7.336
Band 11	31.861	7.399	31.855	7.310
Band 12	43.826	12.017	43.797	11.928
Band 13	42.720	12.058	42.688	11.968
Band 14	44.117	12.641	44.080	12.553
Band 15	40.131	11.642	40.096	11.564
Band 16	33.958	9.738	33.933	9.971
Band 17	30.219	8.601	30.196	8.535
Band 18	39.401	10.497	39.363	10.423

Power spectrum of striped image and power spectrum of modified image are compared in Fig. 7 [8].

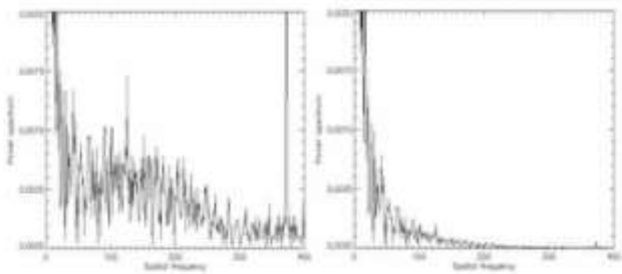
Fig 7: An example of power spectrum of noisy and striped imaged before (left) and after modification (right) taken by CHRIS sensor[8]

4. Conclusion

After an introduction to CHRIS sensor, the reasons for striped noise creation in sensor images affected by electronic noise were discussed. Then horizontal noise and modification methods were introduced. Since the entire row will not be lost and it would happen for even pixels, it is less complicated than vertical noises and stripped images. In the last part some algorithms were proposed to modify vertical noises like histogram modification and filtering method. These methods were implemented on noisy images. Also there was a comparison between all these images. It was shown in the last part that these modifications will not change the radiometric information of de-striped images and it is an advantage of this method compared to stripe noise cancellation in CHRIS sensor images.

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