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A Rapid Method for Correcting Noise in SPOT Imagery

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***Abstract* — SPOT satellite images have many applications in monitoring environmental phenomena because of their good spatial resolution. Unfortunately, there are several types of noise originating from systemic disorders in these images. Due to their low amplitude, these noises more exposed in images acquired from dark scenes as well as in images that are homogeneous in radiometric terms. on the other hand, to remove these types of noises, images should not be geometrically corrected (images should be at pre-processing 1A stage). These noises are seen in the resulting images in HRV sensor's panchromatic band as horizontal, vertical and diagonal striping (the so-called chess-pattern noise) with a period of two pixels. In this paper, a filter is designed to restore noisy images. To evaluate the effectiveness of the filter it was applied to the noisy SPOT images.**

***Keyword* — Noise, Satellite imagery, SPOT, Remote sensing**

1. Introduction

The post-launch investigations of SPOT[1] imagery have revealed some periodic or pseudo-periodic noise. This is most easily noticed in panchromatic images from the second High Resolution Visible (HRV2) where an along-column noise with a period of two pixels and maximum amplitude of about three quantum levels occurs [1]. This line-to-tine noise is coherent along lines, but the amplitude varies along columns. Similar noise, but of lower amplitude, has also been reported for panchromatic images from HRV1, where a corresponding noise in the perpendicular (along lines) was also noticed [2, 3]. In all cases, the dominant period is two pixels, and the amplitude varies only slowly over the image. These noises due to their low amplitude, is a problem in dark scenes with a low dynamic range [4] and make every use of existing data in these images as impossible. Therefore, using the existing data in these images entails eliminating the noises from the images. These noises should not be confused with another, similar type of noise, which was a striping at every seventh column [5]. this occurred only when the images where acquired in double mode (P and XS with the same HRV) and was caused by an interference between the P (panchromatic) and XS (multispectral) channels [4]. This could, however, removed by introducing a special set of calibration factors for the double mode in the pre-processing systems in Toulouse and kiruna [6]. In this field, little work has been done. To remove this types of noises from images, reference [4] designed two types of filters. One filter removes noise in the line and column directions, but the other removes noise in the diagonal direction. The advantages of this method include high-speed processing, high reliability, availability of software for image processing with applicability of apply these filters to images. But the problem with this approach is that to remove each of these noises, a filter has to be designed, which increases the computational complexity. On the other hand, for noise removal, the image must undergo a two-stage filtering which decreases the speed and makes noise removal process time consuming. In this paper, a new combined filter is designed which is faster than the method used by [4] who used two filters to remove noise from the images. Therefore, use of this method is recommended for rapid removal of noise in panchromatic images of HRV2 sensor.

2. Materials and Methods

2.1. Data Used

The data used in this paper, is a SPOT 1 scene acquired over southern Norway on 18 september 1986. The data was recorded in panchromatic mode by HRV2, and pre-processesd to level 1A. it exhibits a line-to-line striping noise with an amplitude of approximately two digital counts. a column-to-column striping noise of slightly less than one digital count is also present.

An enlarged part of the scene is shown in figure 1. It is typical of the area, with lakes, outcropping bedrock and a road. The scene is very dark, due to low reflecting land cover and low sun elevation, resulting in a very small dynamic range of digital counts. This cause the signal-to-noise ratio to be very low, almost preventing any meaningful use of the data.

[1]. Satellite Pour l'Observation de la Terre

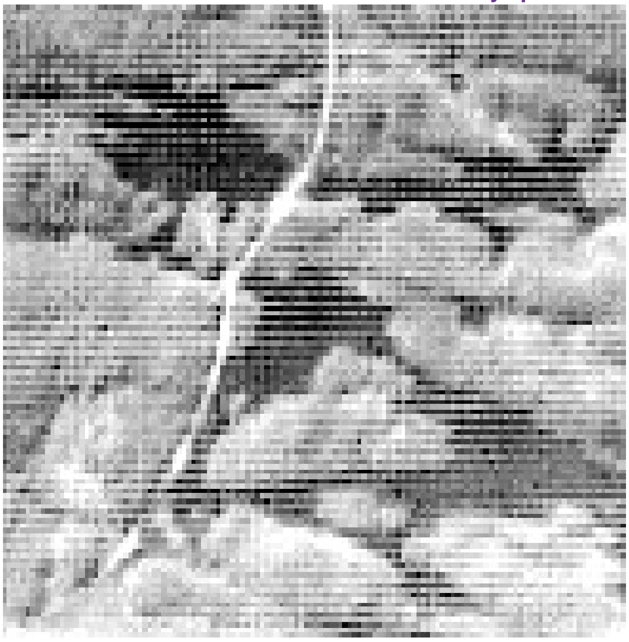

Fig. 1. A sample 128 × 128 pixel of SPOT 1 scene

2.2. Noise removal method

A prerequisite for any successful suppression of this kind of noise is that the image is still in a geometrically raw stage. After re-sampling, the noise will not longer be coherent along lines and columns, as it will be distorted by geometric transformation [4]. In this paper, filtering noisy images is preferred to other methods because of fast processing, and also the capability of digital image processing softwares for filtering digital images. To remove these noises from an image, a combined filter is designed. We designed This filter by MATLAB (R2011a) toolbox for designing two-dimensional Finite Impulse Response (FIR) filters. To remove noise from panchromatic images of HRV2 sensor, the components of the image in the frequency domain with separate and common high frequencies in x and y directions should be eliminated. Therefore, the ideal filter transfer function is given by:

$$H_{(F_x,F_y)} = \begin{cases} 0 & (|F_x|, |F_y|) = (\pi, \pi) \\ 0 & (|F_x|, F_y) = (\pi, 0) \\ 0 & (F_x, |F_y|) = (0, \pi) \\ 1 & \text{otherwise} \end{cases} \qquad (1)$$

To calculate the Impulse Response, we used the windowing method in MATLAB. After calculating the impulse response of the filter, the coefficient matrix for the discrete 15 × 15 filter in the spatial domain is as follows:

0	0	0	0	0	0	0	- 3910	0	0	0	0	0	0	0
0	0	0	0	1850	4240	1960	- 2550	1960	4240	1850	0	0	0	0
0	0	0	-2190	2080	-10800	8270	-2580	8270	-10800	2080	-2190	0	0	0
0	0	-2190	-520	3130	-8310	10000	-30200	10000	-8310	3130	-520	-2190	0	0
0	1850	2080	3130	6760	3090	11170	24090	11170	3090	6760	3130	2080	1850	0
0	4240	- 10800	-8310	3090	-38940	23080	-79890	23080	-38940	3090	-8310	-10800	4240	0
0	1960	8270	10000	11170	23080	11080	55620	11080	23080	11170	10000	8270	1960	0
-3910	-2550	-2580	-3020	24090	-79890	55620	867730	55620	-79890	24090	-30200	-2580	-2550	-3910
0	1960	8270	10000	11170	23080	11080	55620	11080	23080	11170	10000	8270	1960	0
0	4240	- 10800	-8310	3090	-38940	23080	-79890	23080	-38940	3090	-8310	-10800	4240	0
0	1850	2080	3130	6760	3090	11170	24090	11170	3090	6760	3130	2080	1850	0
0	0	-2190	-520	3130	-8310	10000	-30200	10000	-8310	3130	-520	-2190	0	0
0	0	0	-2190	2080	-10800	8270	-2580	8270	-10800	2080	-2190	0	0	0
0	0	0	0	1850	4240	1960	- 2550	1960	4240	1850	0	0	0	0
0	0	0	0	0	0	0	- 3910	0	0	0	0	0	0	0

$\times 10^{-6}$

the frequency response curve of the filter is shown in Figure 2. This removes line, column and chess-pattern noises. It should be noted that in this curve, the frequency axis has been normalized.

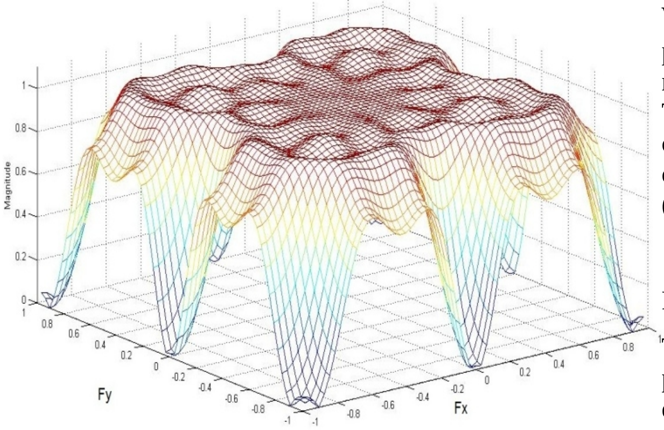

Fig. 2. The frequency response curve of the filter which used for removing noise from panchromatic images of HRV2 sensor

3. Results and Analysis

The filter suggested above was applied to Figure 1 and the result is shown in Figure 3.

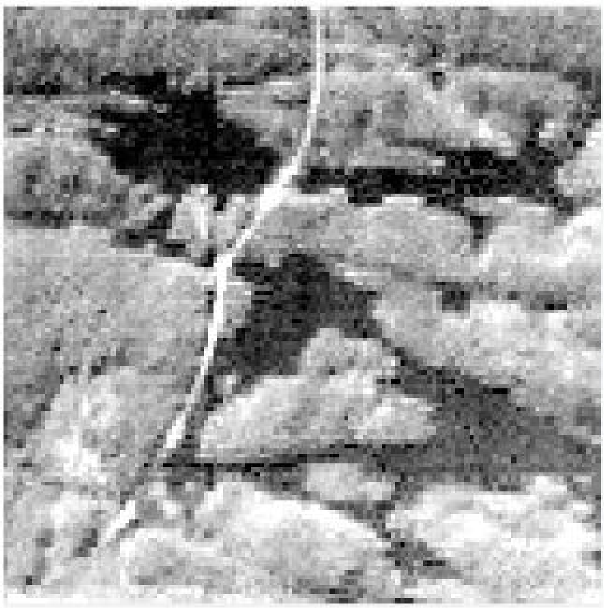

Fig. 3. Result after applying a combined line/column and chess pattern noise removal filter of the size 15 × 15

It is evident that the filter has been effective in removing noise. This method was preferred to other methods because of fast processing and high reliability in noise removal. To apply the filter to the noisy image, we used the digital image processing toolbox of MATLAB. To evaluate and compare the results obtained from the suggested model in this paper with the results obtained by the model presented by [4], we used the Root Mean Square Error (RMSE) (Equation 2). RMSE was calculated between corresponding pixels of filtered images in the two models.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - y_i)^2}{N-1}} \quad (2)$$

Where, x_i is pixels of the filtered image in this paper, y_i is pixels of the filtered image in model [4], and N is the total number of pixels.

The value of the calculated RMSE is equal to 1.73. To calculate the relative error, RMSE is divided by average of the pixels in the filtered image by our model (equations 3 and 4).

$$\text{Average} = \frac{\sum_{i=1}^{N} x_i}{N} \quad (3)$$

$$\text{Relative-Error} = \frac{RMSE}{Average} \quad (4)$$

The error rate calculated for the model proposed in this paper as compared to the model that presented in [4] is equal to 0.8 percent, which indicates that the model in this paper has an accuracy of 99.2 percent. Scatter plot for pixels between images filtered by the proposed model in this paper and the model presented by [4] is shown in Figure 4.

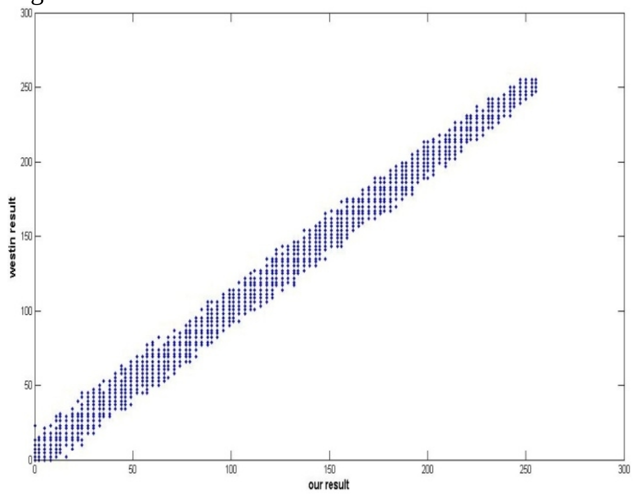

Fig. 4. Scatter plot of pixels for comparing images filtered by the model proposed in this paper and the model presented by [4]

Dispersion around the bisector of the first quadrant is indicative of high accuracy of the model. Noise removal is significance in some cases, for example, when a water boundaries is going to be determined. By setting a threshold level for the raw and filtered images, the water boundaries are specified. To apply the threshold to the images, we used BILkO software. To apply threshold to an image, the pixels with digital counts lower than the threshold are made zero and the values of the rest of the pixels remain intact. The result from thresholding the raw image (the image shown in Figure 1) is shown in Figure 5.

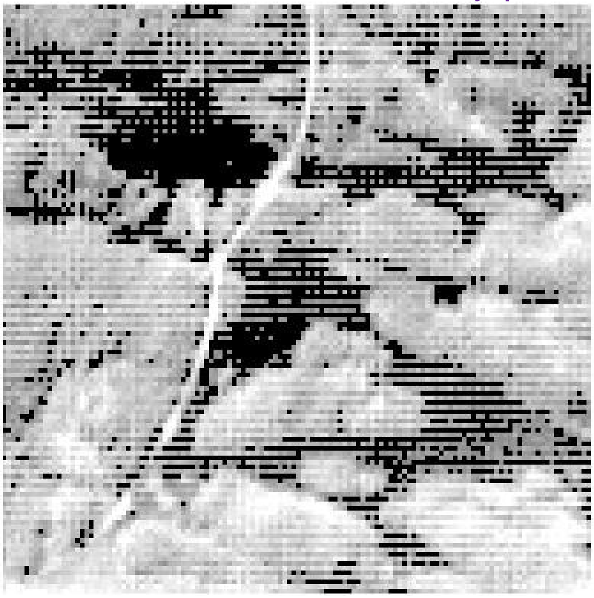

Fig. 5. An attempt to create a water mask in the unfiltered image

As seen, it is impossible to extract the lake boundaries because the noise amplitude is large enough to cause an overlap in the range of digital counts in the water and on land. Figure 6 shows the same operation applied to the filtered image (figure 3). The improvement is quite obvious.

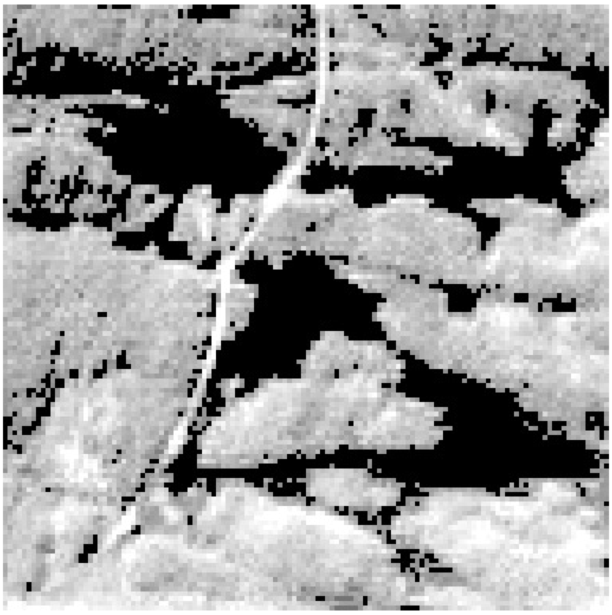

Fig. 6. The effect of thresholding the filtered image in figure 3

4. CONCLUSION

The type of coherent noise that is present in SPOT scene is in some cases strong enough to make some kind of noise suppression vitally important. By addressing this problem while the scene is still in a geometrically raw stage, it is possible to derive filters that effectively remove the noise. Geometric corrections alter noise from the initial state and make it difficult to remove. In this paper, a method is suggested for reducing noises resulting from interference between electronic devices and equipment of HRV2 sensor in the images acquired by the sensor in the panchromatic band. This method was compared by the method presented in [4]. The results of this comparison indicate the accuracy of the method presented in this paper. To evaluate filter performance, a threshold was applied to the raw image and the filtered image for specifying the water boundaries and the results were compared. The low dynamic range of the image on the one hand, and the strong amplitude of the noise on the other hand, cause an overlap between digital counts of the water and on land. Therefore, thresholding the raw image did not have desired results. However, after applying a threshold to the filtered image, water boundaries became obvious, which shows the effectiveness of the filter in noise removal.

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