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Technical note

Filters for removing coherent noise of period 2 in SPOT imagery

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Abstract. Geometrically uncorrected SPOT imagery often displays a very regular horizontal and vertical striping with a period of two pixels. A chess-pattern noise of the same period can also be observed. General expressions for digital filters for the removal of this type of noise are derived. The filters are then applied to a severely noisy SPOT scene to verify their effectiveness.

1. Introduction

The post-launch investigations of SPOT 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 (Begni *et al.* 1986). This line-to-line 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 (Fusco *et al.* 1986), where a corresponding noise in the perpendicular direction (along lines) was also noticed. In all cases, the dominant period is two pixels, and the amplitude varies only slowly over the image. This noise was most pronounced during the first year of operation, but has subsequently diminished in magnitude and is now only a problem in dark scenes with a low dynamic range.

This should not be confused with another, similar type of noise, detected during the first year of operation, which was a striping at every seventh column (Quarmby *et al.* 1986). This occurred only when the images were 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. This could, however, be removed by introducing a special set of calibration factors for the double mode in the pre-processing systems in Toulouse and Kiruna and is no longer a problem (Begni 1988).

2. Methods for noise removal

A prerequisite for any successful suppression of this kind of noise is that the image is still in a geometrically raw stage (level 1A). After resampling, the noise will not longer be coherent along lines and columns, as it will be distorted by the geometric transformation.

As the along-column noise is coherent along lines, one obvious way to remove it is to apply constant shifts to each line. The shift can be calculated by comparing the average intensity over the line with the corresponding averages of a neighbourhood of lines. This method was tested and found to work well, both for the along-column and the along-line noise.

A disadvantage of this approach, however, is that the computational cost is quite high. A filter approach would be preferable as it would normally result in much faster processing, utilizing fast filtering programs already available at most image processing facilities.

To be able to test the feasibility of convolution filtering for the reduction of noise in SPOT images, general expressions for two types of period-2 frequency filters was derived. One will remove noise in the line and column direction, while the other will remove noise in the diagonal direction.

3. Period-2 noise-removal filters

The transfer function of an ideal period-2 band-stop filter in the line and column directions is given by

$$G(u,v)=\begin{cases} 0 & (|u|,v)=(\frac{1}{2},0) \\ 0 & (u,|v|)=(0,\frac{1}{2}) \\ 1 & \text{elsewhere} \end{cases}$$

where u and v are frequencies in the x and y directions respectively. Computing the impulse response and sampling it, gives the following discrete filter coefficients for a filter of size $(2M+1)\times(2N+1)$:

$$c_{ij}=\begin{cases} 1-\dfrac{1}{4NM}[\cos(\pi i)+\cos(\pi j)] & i=0, j=0 \\ -\dfrac{1}{4NM}[\cos(\pi i)+\cos(\pi j)] & \begin{matrix} 0<|i|<N \\ 0<|j|<M \end{matrix} \\ -\dfrac{1}{16NM}[\cos(\pi i)+\cos(\pi j)] & |i|=N,\ |j|=M \\ -\dfrac{1}{8NM}[\cos(\pi i)+\cos(\pi j)] & \begin{matrix} |i|=N,\ |j|<M \\ |i|>N,\ |j|=M \end{matrix} \\ 0 & |i|>N,\ |j|>M \end{cases}$$

Evaluating this for a kernel size of 9×9 results in the following coefficients:

$$\begin{bmatrix} -781 & 0 & -1562 & 0 & -1562 & 0 & -1562 & 0 & -781 \\ 0 & 3125 & 0 & 3125 & 0 & 3125 & 0 & 3125 & 0 \\ -1563 & 0 & -3125 & 0 & -3125 & 0 & -3125 & 0 & -1562 \\ 0 & 3125 & 0 & 3125 & 0 & 3125 & 0 & 3125 & 0 \\ -1562 & 0 & -3125 & 0 & 96875 & 0 & -3125 & 0 & -1562 \\ 0 & 3125 & 0 & 3125 & 0 & 3125 & 0 & 3125 & 0 \\ -1562 & 0 & -3125 & 0 & -3125 & 0 & -3125 & 0 & -1562 \\ 0 & 3125 & 0 & 3125 & 0 & 3125 & 0 & 3125 & 0 \\ -781 & 0 & -1562 & 0 & -1562 & 0 & -1562 & 0 & -781 \end{bmatrix}\times 10^{-5}$$

While testing this filter on real SPOT data, a residual chess-pattern component of noise was noticed in the filtered image. This is also noise of period-2, but in a diagonal direction. A filter to remove a chess-pattern would ideally have the transfer function

$$G(u,v)=\begin{cases} 0 & (|u|,\,|v|)=(\tfrac{1}{2},\,\tfrac{1}{2}) \\ 1 & \text{elsewhere} \end{cases}$$

which gives the following discrete filter coefficients:

$$c_{ij}=\begin{cases} 1-\dfrac{1}{4NM}\cos(\pi i)\cos(\pi j) & \mathrm{i}=0,\, j=0 \\[2ex] -\dfrac{1}{4NM}\cos(\pi i)\cos(\pi j) & \begin{array}{l} 0<|i|<N \\ 0<|j|<M \end{array} \\[2ex] -\dfrac{1}{16NM}\cos(\pi i)\cos(\pi j) & |i|=N,\ |j|=M \\[2ex] -\dfrac{1}{8NM}\cos(\pi i)\cos(\pi j) & \begin{array}{l} |i|=N,\ |j|<M \\ |i|<N,\ |j|=M \end{array} \\[2ex] 0 & |i|>N,\ |j|>M \end{cases}$$

Evaluating this for a kernel size of 9×9 results in

$$\begin{bmatrix} -391 & 781 & -781 & 781 & -781 & 781 & -781 & 781 & -391 \\ 781 & -1563 & 1563 & -1563 & 1563 & -1563 & 1563 & -1563 & 781 \\ -781 & 1563 & -1563 & 1563 & -1563 & 1563 & -1563 & 1563 & -781 \\ 781 & -1563 & 1563 & -1563 & 1563 & -1563 & 1563 & -1563 & 781 \\ -781 & 1563 & -1563 & 1563 & 98438 & 1563 & -1563 & 1563 & -781 \\ 781 & -1563 & 1563 & -1563 & 1563 & -1563 & 1563 & -1563 & 781 \\ -781 & 1563 & -1563 & 1563 & -1563 & 1563 & -1563 & 1563 & -781 \\ 781 & -1563 & 1563 & -1563 & 1563 & -1563 & 1563 & -1563 & 781 \\ -391 & 781 & -781 & 781 & -781 & 781 & -781 & 781 & -391 \end{bmatrix}\times 10^{-5}$$

4. Filter performance evaluation

The filters given above were applied to a SPOT scene (K/J 042/231) acquired over southern Norway on 18 September 1986. The data was recorded in panchromatic mode by HRV2, and preprocessed to level 1A. It exhibits 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 causes the signal-to-noise ratio to be very low, almost preventing any meaningful use of the data.

The result of applying the line and column noise removal filter is shown in figure 2. The filter kernel size was 9×9 in this case. It is obviously quite effective in removing the striping. However, while not detected before because of its low amplitude, we now see a weak chess-pattern when examining the lake areas. The result of applying a combined line/column and chess-pattern filter of the size 9×9 to the raw data is shown in figure 3. It seems to be slightly more effective, as it reduces the chess-pattern while still performing as well in reducing the line and column noise.

The importance and success of noise reduction becomes very obvious when trying

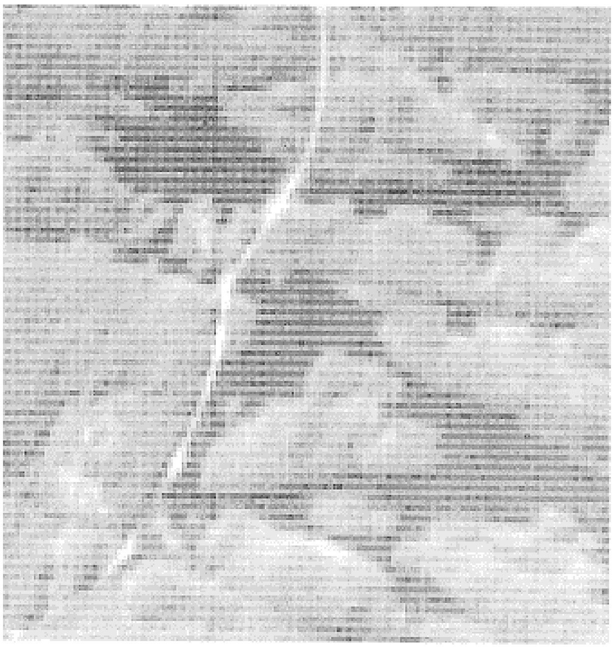

Figure 1. A sample 128 × 128 pixel window from the SPOT scene 042-231 of 18 September 1986. The scene has been preprocessed to level 1A (no geometric correction) and a linear contrast sketch has been applied. The amplitude of the horizontal striping is around two digital counts before the contrast stretch. © Copyright CNES 1986.

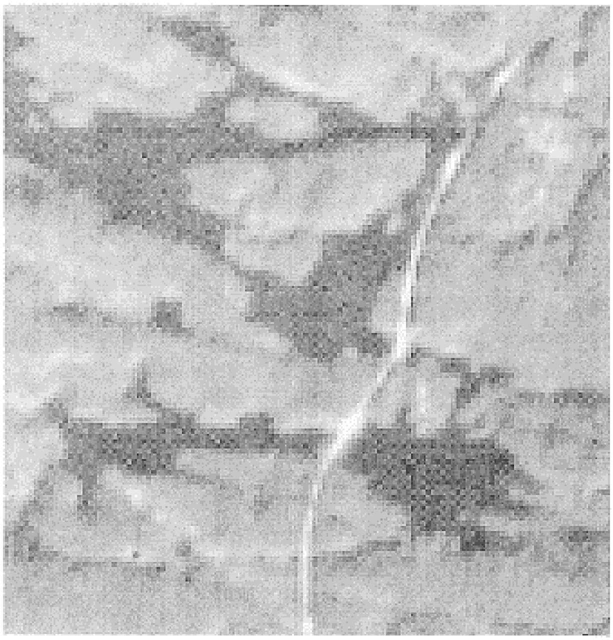

Figure 2. Result after applying a line and column noise removal filter of size 9 × 9. © Copyright CNES 1986.

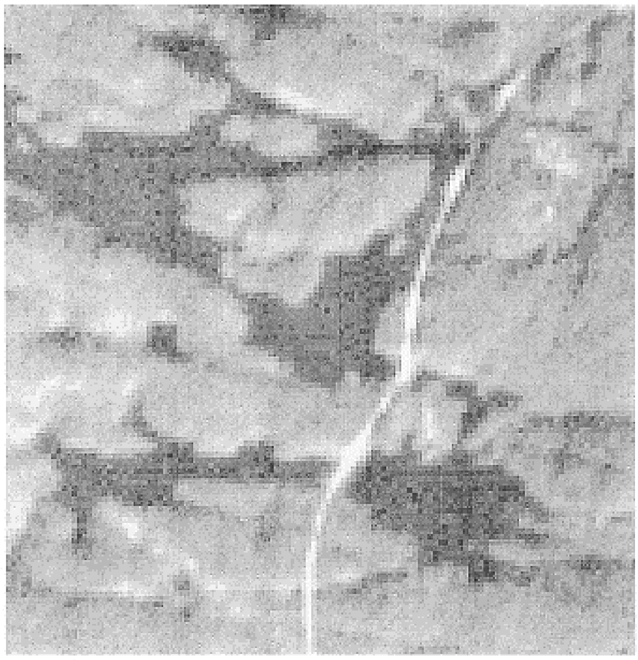

Figure 3. Result after applying a combined line/column and chess-pattern noise-removal filter of the size 9 × 9. © Copyright CNES 1986.

Figure 4. An attempt to create a water mask in the unfiltered image of figure 1, by using an intensity threshold, setting all pixels that are below the threshold to zero. © Copyright CNES 1986.

Figure 5. Same as in figure 4, but using a threshold one digital count higher. © Copyright CNES 1986.

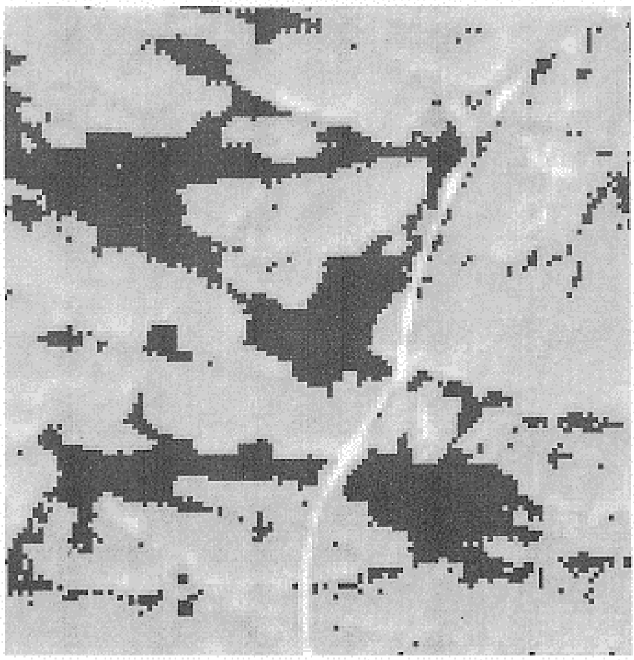

Figure 6. The effect of thresholding the filtered image in figure 3. © Copyright CNES 1986.

to create a water mask by thresholding the image. The extraction of waterboundaries is very important in many remote sensing applications, as well as in some digital image matching methods. Figures 4 and 5 show the result from thresholding at two adjacent digital levels in the raw image, setting all pixels lower than the threshold to zero. 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 (in figure 3). The improvement is quite obvious.

5. Conclusion

The type of coherent noise that is present in SPOT scenes 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. After geometric correction and resampling, the very stable Nyquist frequency component of the raw image noise would have been more or less distorted. This has lead to the decision to include these filters as a standard tool in the production of precision corrected SPOT products at Satimage.

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