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Destriping remote sensing images using frequency domain Butterworth notch filter

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Abstract— **Nowadays, satellite images are widely used for local phenomena monitoring. Unfortunately, some striping noises are observed in these images caused by imperfect calibration of detectors, imperfect image processing in ground receiving stations, detector failure and so on which lead to reduced data quality. Thus, for any useful application of data contained in these images, noises should be removed firstly. In this paper, frequency domain Butterworth notch filter has been used for removal of periodic striping noises in satellite images. This method is simpler and of high accuracy compared to some existing methods. Therefore, it is proposed to use this method for removal of periodic striping noise in satellite images**

Index Terms— periodic striping noise; Butterworth notch filter; Fourier transform; remote sensing.

I. INTRODUCTION

Nowadays, remote sensing images are widely used for environmental researches and scientific studies. Unfortunately, existence of some noises makes using data contained in these images difficult or even impossible. Therefore, noise removal should be carried out in order to use the data in these images. The most common type of image noises in satellite images, are striping noise which are introduced into an image as a result of factors such as imperfect calibration of detectors, imperfect image processing in ground receiving stations and detector failure [8].Noise removal process should be so that does not influence on image main contents and only remove the noise. In [1] radiometric equalization techniques have been applied primarily to remove non-periodic striping in image data. In these techniques a simple gain and bias model is developed for all detectors and then used for compensation. This method does not account for nonlinearity in sensor variations. [2] for correcting striping noise from images has employed histogram modification. In this approach the histogram of the noisy data is made to match a histogram of suitable reference data. This suitable reference histogram can be the global histogram of the image, can be from some other compatible image, or can be from one of the detectors considered as the reference with histogram data from other detectors matched to it. These techniques are easily implemented but can involve trial and error and inconsistent results. [3] has used the principal components analysis to remove noisy scan lines from TM images. After the principal components are obtained, the noisy higher order components are simply set to zero and an inverse transformation is performed. Though this method is effective, it involves an enormous amount of computation to compute statistics and eigenvectors and then apply the forward and inverse transformations. [4] has employed power spectra filtering method to remove periodic striping noise in Landsat images. In this method, image is divided into several parts and Fourier transform is taken from each part and power spectra of the image is calculated. After a series of enhancements on power spectra, inverse Fourier transform is taken in order to obtain convolution kernel. However, the problem with this method is that many enhancements should be done on power spectra to obtain convolution kernel. [5] has employed line tracking and edge detection algorithms for locating striping patterns in satellite images. After detecting these patterns, striping noise is removed using spatial curve functions. The advantage of this method is that it can remove non-periodic striping noise from the image as well. The problem with this method is that it detects some additional strips when detecting striping patterns locations in images. [7] has used spatial domain image filtering for removal of periodic striping noise in panchromatic images acquired by SPOT second High Resolution Visible (HRV2). This method is a relatively fast method. However, the problem with this method is that the filter may affect other image factors as well as noise removal.

In this paper, frequency domain Butterworth notch filter has been used for removal of periodic striping noise in satellite images. This method is of high accuracy as it removes only noise components in frequency domain. Finally, to compare the proposed method here with methods provided in [4] and [7], Peak Signal to Noise Ratio (PSNR) has been calculated and resulting findings show the proposed method accuracy. It should be noted that for implementing the model and noise

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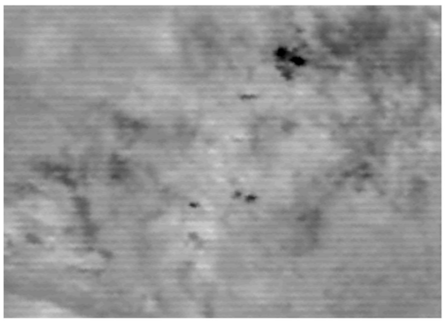
removal, digital image processing toolbox of MATLAB software (MATLAB 7.12.0 (R2011a)) has been employed.

II. material and methods

A. data

The data used in this paper, have been acquired by Landsat 5 Thematic Mapper, Landsat 4 Multi Spectral Scanner (MSS) and SPOT 1 second High Resolution Visible. Figure 1(a) shows a sample image acquired in band 6 of Landsat 5 Thematic Mapper. Figure 1(b) shows a sample image acquired in band 2 of Landsat 4 MSS which includes periodic striping noise. This kind of noise is observed in Landsat 4 and 5 MSS and TM Level 0 and level 1T data [8].



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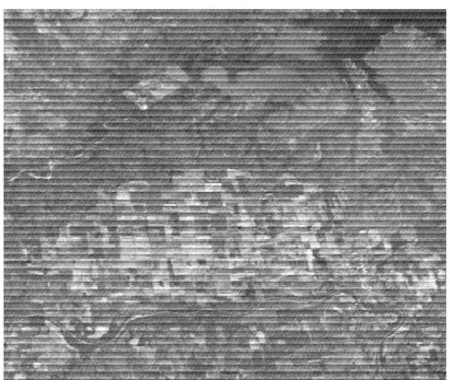

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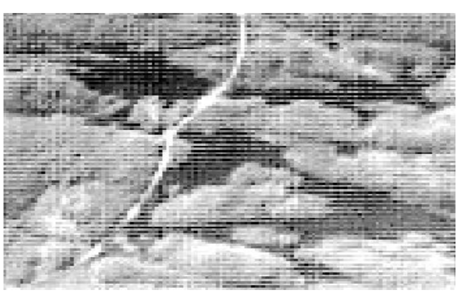


c

Fig: 1. (b): a 360*360 pixels sample of striping in Landsat 5 Thematic Mapper level 1T data. (b): a 360*360 pixels sample of striping in Landsat 4 Multi Spectral Scanner level 0 data. (c): a 128*128 pixels of SPOT 1 scene.

Figure 1(c) shows a part of the acquired image in panchromatic band of SPOT 1 HRV2 which has been pre-processed at level 1A and includes periodic striping noise [7].

B. Destriping algorithm

One of the important topics in remote sensing is noise removal from images so that noise removal process does not influence on image main contents and only remove the noise. Spatial domain noise components detection is a difficult task. Therefore, to detect noise components, the image should be transferred to a space in which noise components will be distinguishable from other components. In this paper, Fourier transform was taken from the image and Fourier spectrum of the image was calculated to detect noise components. Fourier spectrum was calculated according to the following equation:

$$|F_{(u,v)}| = [R^2{}_{(u,v)} + I^2{}_{(u,v)}]^{1/2} \quad (1)$$

Where $R_{(u,v)}$ and $I_{(u,v)}$ denotes the real and imaginary parts of Fourier transform respectively. Existence of periodic striping noise in image cause bright spots in Fourier spectrum. Thus, periodic striping noise components can be detected using Fourier spectrum. After detecting noise components in Fourier spectrum, the magnitude of these components in image Fourier transform can be reduced to zero using Butterworth notch filter. Transfer function of Butterworth notch filter has been shown in Equation (2):

$$H_{(\mathrm{u,v})} = \frac{1}{1+\left[\frac{D_0{}^2}{D_{1(u,v)}D_{2(u,v)}}\right]^n} \quad (2)$$

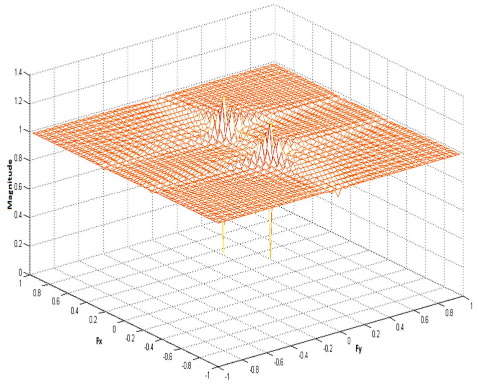
Where D_0 denotes notch radius and n denotes the filter order. $D_{1(\mathrm{u,v})}$ and $D_{2(\mathrm{u,v})}$ have been shown in Equations (3) and (4) respectively:

$$D_{1(\mathrm{u,v})} = [(u - M/2 - u_0)^2 + (v - N/2 - v_0)^2]^{1/2} \quad (3)$$

$$D_{2(\mathrm{u,v})} = [(u - M/2 + u_0)^2 + (v - N/2 + v_0)^2]^{1/2} \quad (4)$$

Where M and N are image dimensions and (u_0 , v_0) is the notch locations. After locating the noise components in Fourier spectrum (determining v_0 and u_0), filter reduces the magnitude of striping noise components in image Fourier transform to zero. After that, we take inverse Fourier transform from justified Fourier transform of image to restore the corrected image.

Frequency response of the designed filters are shown in figure 2. As can be seen in the curves, Filters have the least amount of ripple And also have sharp edges. It should be noted that in these curves, the frequency axis has been normalized.



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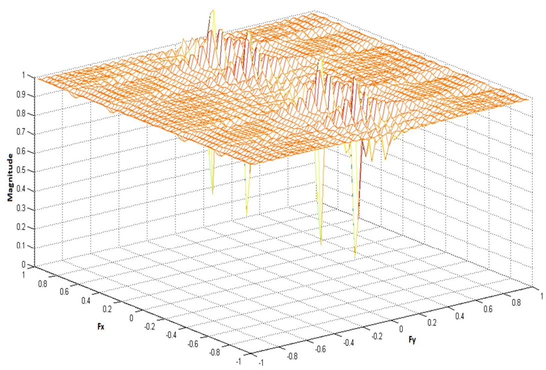

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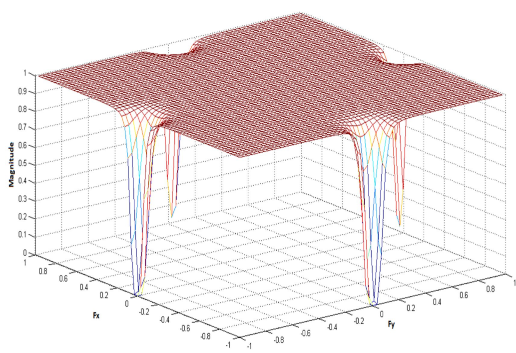

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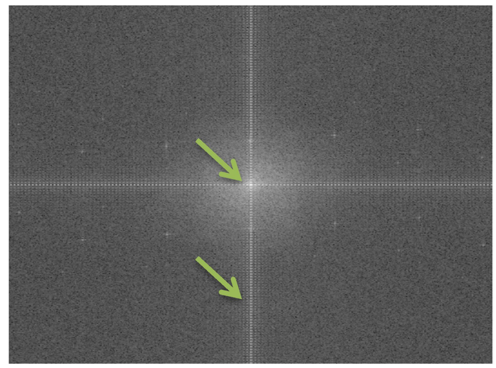
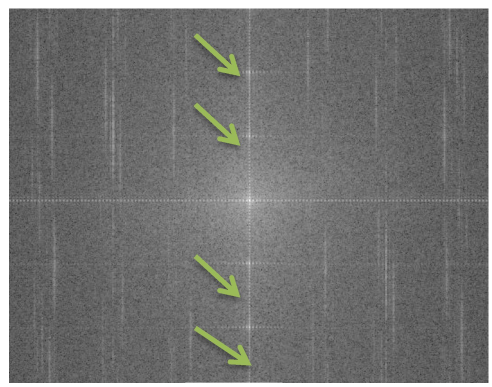
Fig: 2. The frequency response curve of the filters to remove the noise in images that shown in figure 1 (a), (b) and (c).

III. result and discussion

Proposed method in previous section was applied to the images in Figure 1. As indicated in Figure 3, periodic striping noise components in image Fourier spectrum are observed as a series of bright spots. Therefore, periodic striping noise components can be located using Fourier spectrum. It should be noted that the bright spot in the center of Fourier spectrum represents zero frequency components. Figure 3(a) shows Fourier spectrum of the image in figure 1.a and similarly, Figure 3(b) and 3(c) shows Fourier spectrum of the images in Figure 1(b) and 1(c) respectively.

After locating the noise components in Fourier spectrum, noise can be removed from the images using frequency domain Butterworth notch filter. The results of noise removal for images in figure 1 are shown in Figure 4. Visual investigations show the effectiveness of the proposed method in noise removal. Also, Fourier spectrum of the corrected images have been shown in Figure 5. As it can be seen, bright spots in Fourier spectrum of raw images do not exist in Fourier spectrum of the corrected images, indicating noise removal from images.





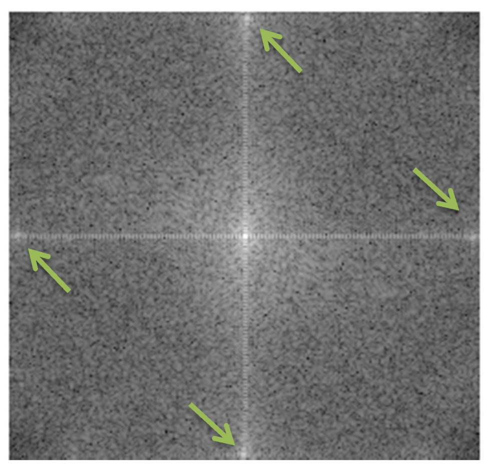


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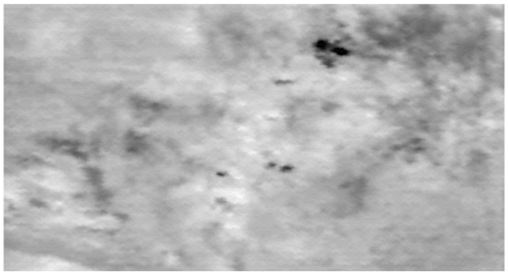
Fig: 3. (a): Fourier spectrum of the image in Fig. 1 (a). (b):Fourier spectrum of the image in Figure 1(b). (c):Fourier spectrum of the image in Figure 1(c). As it can be seen, noise components are seen as bright spots in Fourier spectrum.



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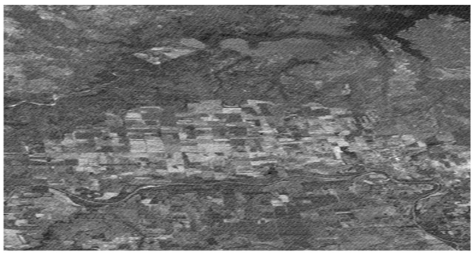

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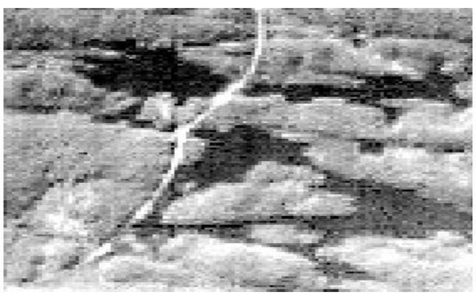

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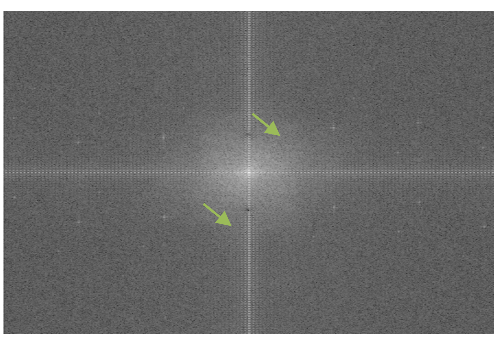
Fig: 4.(a), (b) and (c): The result of noise removal for the images in Figure 1(a), (b) and (c), respectively



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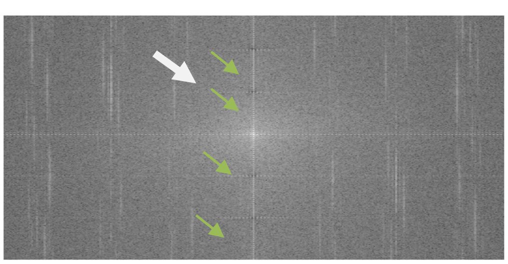

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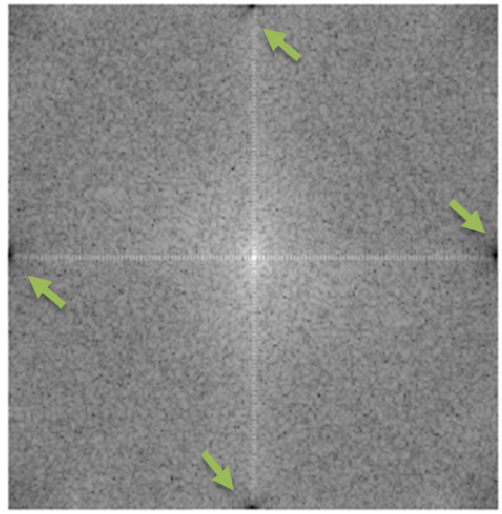

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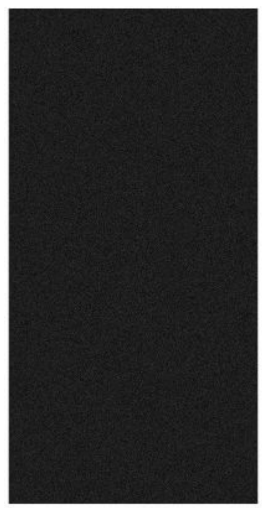
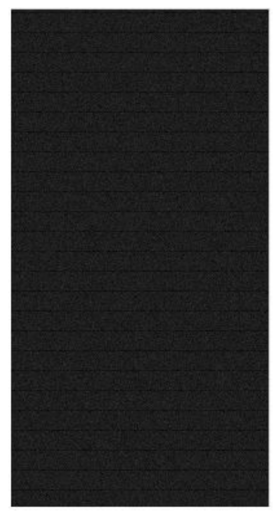
Fig: 5. (a): Fourier spectrum of the image in Figure 3(a). (b): Fourier spectrum of the image in Figure 3(b).(c): Fourier spectrum of the image in Figure 3(c). As it can be seen, bright spots related to noise are not seen in Fourier spectrum of enhanced images.



a



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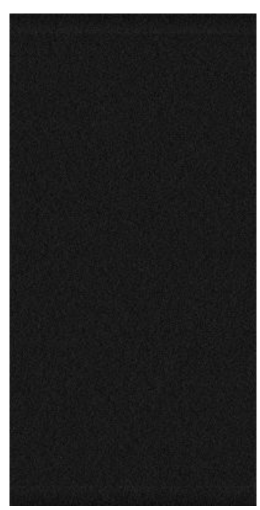

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Fig: 6. A) Raw data. B) Simulated data for vertical striping noise. C) The result of striping noise removal in figure (b)

To demonstrate the efficacy of the proposed method in noise removal, a simulated data has been used for periodic striping noise. Raw data is shown in Figure 7 (a) that after adding the periodic striping noise, it is shown in Figure 7 (b). Also in Figure 7 (c) the result of destriping has been shown.

To compare the results obtained from the suggested model in this paper (figure 6 (c)) with the original image (figure 6 (a)), we used the Root Mean Square Error (RMSE) (Equation 5). RMSE was calculated between corresponding pixels of the modified image and original image.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(x_i - y_i)^2}{N-1}} \quad (5)$$

Where, x_i is pixels of the corrected image, y_i is pixels of the original image, and N is the total number of pixels.

The value of the calculated RMSE is equal to 1.60. To calculate the relative error, RMSE is divided by average of the pixels in the filtered image by our model (equations 6 and 7).

$$Average = \frac{\sum_{i=1}^{N} x_i}{N} \quad (6)$$

$$Relative\text{-}Error = \frac{RMSE}{Average} \quad (7)$$

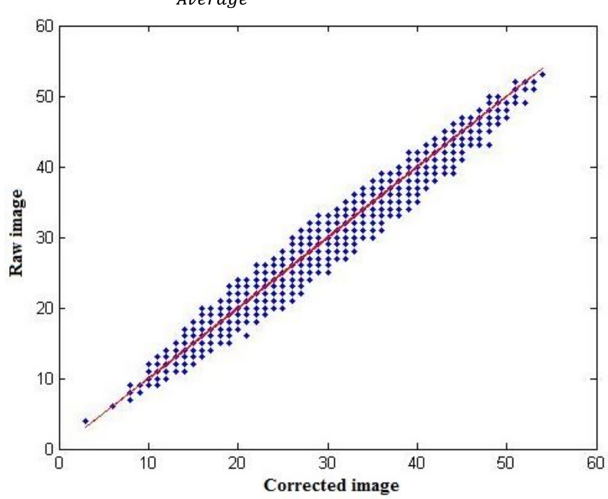

Figure 7. The Scatter plot drawn between Figure 6 (a) and 6 (c)

The error rate calculated for the result of the model proposed in this paper as compared to original image is equal to 6.31 percent, which indicates that the model has an accuracy of 93.7 percent in noise removal. To evaluate the model, scatter plot of pixels is drawn between the initial image (Fig. 6 (a)) and the corrected image (Fig. 6 (c)). This diagram is shown in Figure 8. Dispersion of points around the bisector of the first quadrant shows the accuracy of the model in noise removal and little error of the method in noise removal. Figure 8 shows the histogram of the simulated data. As this chart suggests, the noise removal algorithm has a negligible impact on the content of the original image, but it was somehow successful in the noise removal.

In Table 1, the statistical characteristics of images (figure1 and 4) before and after the destriping are given. The reduction seen in the standard deviation is due to the noise removal, because presence of the noise in the image increases this quantity.

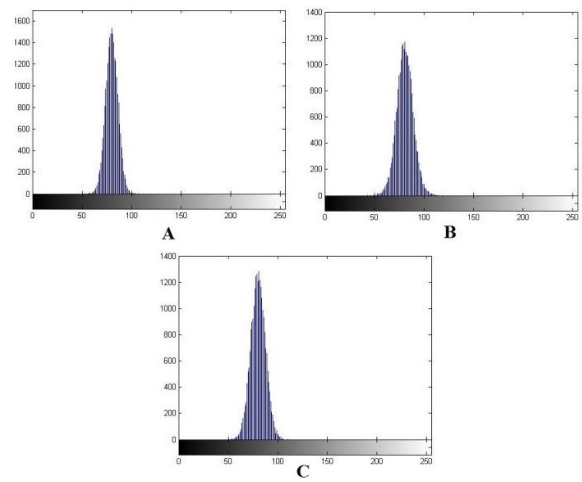

Figure 8. A) histogram of image in Figure 6 (a). B) histogram of image in Figure 6 (b). C) histogram of image in Figure 6 (c)

	mean	Standard deviation
The image in figure 1(a)	150.42	3.59
The image in figure 4(a)	146.85	2.96
The image in figure 1(b)	79.32	23.15
The image in figure 4(b)	79.37	10.83
The image in figure 1(c)	50.80	40.37
The image in figure 4 (c)	48.29	19.29

Table 1: The calculated mean and Standard deviation for the raw and corrected images

In addition to standard deviation, the PSNR also calculated. It is obvious that more PSNR value, show more accurate of the noise removal method. PSNR mathematical relationship has been shown in Equation (8):

$$PSNR = 10 \log \left(\frac{D^2 \times M \times N}{\sum_{j=0}^{M-1}\sum_{i=0}^{N-1}(g_{(i,j)} - f_{(i,j)})^2}\right) \quad (8)$$

Where D for n-bite quantization equals to 2^n. M and N are image dimensions, $f_{(i,j)}$ is the raw image and $g_{(i,j)}$ is the corrected image. Results of comparison between the proposed method here and the methods provided in [4] and [7] have been described in Tables 2 and 3. [4] has used power spectrum filtering to remove noise from Landsat images. Also, [7] has used spatial domain filtering to correct SPOT panchromatic images. As it can be seen, the obtained values for PSNR show the accuracy of the proposed model in this paper. It should be noted that the obtained values are in dB.

	The image in Figure 4(a)	The image in Figure 4(b)
The method used in [4]	36.42	33.21
The method proposed in this paper	37.28	34.11

Table 2: The calculated PSNR for the corrected images in this paper and the model provided in [4]

	The image in Figure 4(c)
The method used in [7]	18.80
The method proposed in this paper	21.14

table 3: The calculated PSNR for corrected images in this paper and the model provided in [7]

conclusion

One of the most important tasks in remote sensing is noise removal from satellite images. Noise removal process should be so that does not influence on main contents of image and only remove the noise. Therefore, providing an accurate method for noise removal from remote sensing images seems greatly important. Existence of noise in images makes extracting data from these images difficult or even impossible. Therefore, noises should be removed to allow using the data contained in these images. One of the most common types of noises in satellite images, are striping noises. These kinds of noises are introduced to images as a result of different factors including imperfect calibration of detectors, detector failure and some other causes. The idea employed in this paper was that the image be transferred to a space in which noise components can be detected and in turn removed. Periodic striping noises in image Fourier spectrum are seen as bright spots. Thus, periodic striping noise components can be detected with transferring image to frequency domain and calculating Fourier spectrum. After Noise components detection, frequency domain Butterworth notch filter was applied. Then, inverse Fourier transform was taken from justified Fourier transform of the image to restore the corrected image. To compare and evaluate the proposed method in this paper, standard deviation and PSNR ratio were used. The results of comparison between the proposed method in this paper and the methods provided in [4] and [7] showed that effectiveness rate of this method was higher than the previous methods. Therefore, using this method for removal of periodic striping noises is proposed.

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