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Stripe Noise Removal from Remote Sensing Images Based on Stationary Wavelet Transform

[1] Jin ZHANG, [1] Yu-Ting MA, [1] Ye YANG, [2] Chang-Cheng SHI, [1] Ying-Xuan LI, [1] Hong-Liang CUI

[1] College of Instrumentation & Electrical Engineering, Jilin University, Changchun, 130061, China
[2] Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing, 400714, China
[1] Tel.: 13224312586, fax: 0431-88502993
[1] E-mail: zhangjin0109@jlu.edu.cn

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Abstract: Fourier transform is applied to detect the direction of stripe noise before de-noising, which is advantageous for selecting the corresponding detail coefficients for threshold quantization after stationary wavelet transform. Depending on the direction of stripe noise, the corresponding detail coefficients contain stripe noise need to be removed, while retaining the approximate coefficients and other detail coefficients. The algorithm can remove stripe noise effectively and preserve original image details as much as possible. In addition, stationary wavelet transform is used for the first time in stripe noise removal from remote sensing images. Compared with the traditional de-noising algorithms based on discrete wavelet transform, stationary wavelet transform can better maintain the details of original image because it is redundant and shift-invariant. As shown in the experiments, the new algorithm reported herein performs better than discrete wavelet transform, mean filter and gauss filter, leading to good visual effects. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Fourier transform, Stationary wavelet transform, Discrete wavelet transform, Stripe noise, Image de-noising.

1. Introduction

The existence of stripe noise seriously degrades image quality and adversely impacts on the subsequent extraction and use of the image information [1-3]. Therefore, it is obviously crucial to look for an effective method which can suppress and eliminate stripe noise. At present, the methods used for eliminating stripe noise are usually divided into the following two categories:

1) One method is to find the specific causes of stripe noise and attempt to eliminate these factors. Stripe noise is almost always due to interference effects, usually caused by spatial overlap of coherent light beams, resulting in periodically spatial variation of the combined light intensity. Thus, when two light waves with the same frequency, polarization, and with a definitive phase difference overlap each other in space, the total light intensity in some areas is strengthened whereas it is weakened in other areas. The strengthened areas and weakened areas are interspersed and separated from one another, leading to the appearance of stripes. Therefore, one can prevent the occurrence of interference phenomenon and inhibit stripe noise through technology improvement of the imaging equipment and the light source.

2) Another method is to employ appropriate de-noising algorithms to remove stripe noise. There are several main stripe noise removal algorithms, such as

histogram matching algorithm [4], moment matching algorithm [5], frequency domain based algorithm [6], etc. Histogram matching algorithm assumes that the radiation intensities of each sensor have similar statistics. Moment matching algorithm assumes that the study area is uniform or quasi uniform, and each row has the same mean and standard deviation following the direction of the sensor's movement. The two algorithms mentioned above have strong limitations, so they are not applicable for many actual complex images. In frequency domain based algorithm, the images with stripe noise are transformed from spatial domain to frequency domain. Generally speaking, the frequencies of stripe noise and useful image information are basically in different positions. Consequently, particular frequency components which represent stripe noise need to be removed, whereas other frequency components remain the same during the de-noising process. However, because stripe noise and useful image information in the frequency domain can't be completely separated sometimes, frequency domain based algorithm will also remove useful image information inadvertently, while removing stripe noise.

In the present work, Fourier transform and stationary wavelet transform are combined to remove stripe noise of remote sensing images, which can maintain detailed image information for the most part and effectively eliminate stripe noise. The latter usually has a certain direction and features either a horizontal distribution or a vertical distribution. It is proposed to first detect the direction of the stripe noise distribution through Fourier transformation. Approximation coefficients, horizontal detail coefficients, vertical detail coefficients, and diagonal detail coefficients are then extracted through stationary wavelet decomposition. On the basis of the detected spatial distribution characteristics of stripe noise, targeted threshold quantization is performed for horizontal detail coefficients, vertical detail coefficients or diagonal detail coefficients. Experimental results demonstrate that the new algorithm proposed here can effectively remove stripe noise from remote sensing images.

This paper is organized as follows: First, the directional detection of stripe noise distribution is presented in section 2. Section 3 introduces stationary wavelet transform. The algorithm based on stationary wavelet transform for removing stripe noise is presented in section 4. Experimental results and analyses are given in section 5. Finally, concluding remarks and a summary are presented.

2. The Directional Detection of Stripe Noise Distribution

Fig. 1 (a) shows the Lena image with added horizontal stripe noise. Fig. 1 (b), (c) and (d) are respectively from Lunar Orbiter Digitization Project [7] and LANDSAT database [8]. The interference appearing in image scanning, transmission and output phases causes stripe noise.

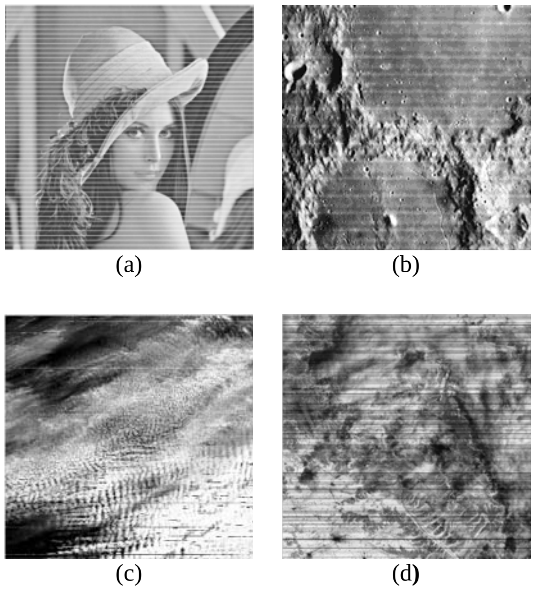


Fig. 1. The images with stripe noise.

Fig. 2 is respectively Fourier frequency spectrogram of every subgraph after translation processing. As can be seen from Fig. 2, for horizontal stripe noise, there is a high brightness elongated line in the central position of vertical direction in the frequency spectrogram, whereas there is no similar elongated line in other directions.

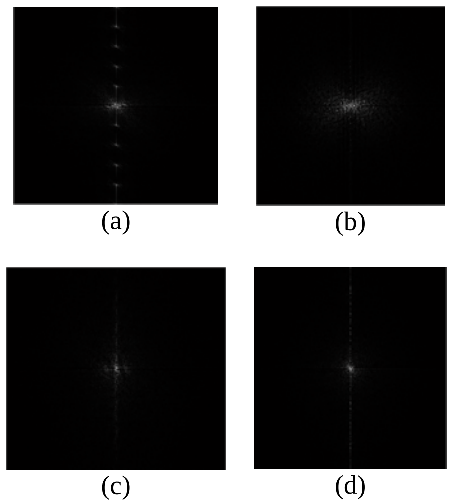


Fig. 2. Fourier frequency spectrogram after the process of translation.

Therefore, we can judge whether horizontal stripe noise exist according to this feature. Similarly, when vertical stripe noise exists, there is a high brightness elongated line in the central position of horizontal direction in the frequency spectrogram. The reasons of high brightness vertical elongated line appearing in the frequency spectrogram are as follows:

A two-dimensional discrete Fourier transform is performed on the image with stripe noise.

$$F(u,v) = \frac{1}{N}\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f(x,y) e^{-j2\pi(\frac{ux}{N}+\frac{vy}{N})} \quad (1)$$

A new equation is obtained from the above equation through a simple transformation.

$$F(u,v) = \frac{1}{\sqrt{N}}\sum_{x=0}^{N-1}\left[\frac{1}{\sqrt{N}}\sum_{y=0}^{N-1} f(x,y) e^{-j2\pi(\frac{ux}{N})}\right] e^{-j2\pi(\frac{vy}{N})} \quad (2)$$

From the transformed equation, we can see that two-dimensional Fourier transform is actually made up of two one-dimensional Fourier transforms, which first calculates one-dimensional Fourier transform in the row (horizontal) direction, and then calculates one-dimensional Fourier transform in the column (vertical) direction. Hence, the frequency spectrogram is divided into horizontal component (u component) and vertical component (v component) after two-dimensional Fourier transform. It is generally known that the image frequency represents the intensity of gray changes. For the image with horizontal stripe noise, gray changes in the vertical direction are comparatively intense, so a high brightness elongated line appears in the vertical direction of frequency spectrogram. The line will appear in the central position of frequency spectrogram after the process of translation. The function of translation is to make positive axis and negative axis of frequency spectrogram centro-symmetric.

3. Stationary Wavelet Transform

Stationary wavelet transform was proposed on the basis of discrete wavelet transform by Nason in 1995 [9]. It is a redundant wavelet transform and has shift-invariance. Compared with classical discrete wavelet transform, the differences of stationary wavelet transform lie in: (1) After low-pass and high-pass filter, input signals of discrete wavelet transform are required to perform one-out-of-two down sampling, so the number of approximation coefficients and detail coefficients after discrete wavelet transform will halve with the increase of wavelet decomposition level. But stationary wavelet transform does not perform down sampling. As a result, the length of approximation coefficients and detail coefficients are the same as with the original signal. Thus it can be seen that stationary wavelet transform has redundancy. (2) Discrete wavelet transform is sensitive to the displacement of input signals. A tiny displacement of input signals will cause large changes of wavelet transform coefficients, while stationary wavelet transform is not sensitive to the displacement of input signals and has shift-invariance.

The two-step decomposition process of stationary wavelet transform is as shown in Fig. 3. CA, CD^H, CD^V, CD^D are respectively approximation coefficients, horizontal detail coefficients, vertical detail coefficients and diagonal detail coefficients. Because low frequency information is concentrated on approximation coefficients and high frequency information is concentrated on detail coefficients, we make threshold quantization on detail coefficients and keep approximate coefficients constant during de-noising process.

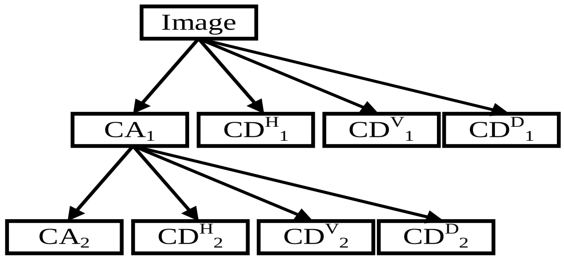


Fig. 3. The stationary wavelet decomposition of the 2-layer.

4. Our Algorithm Described in This Paper

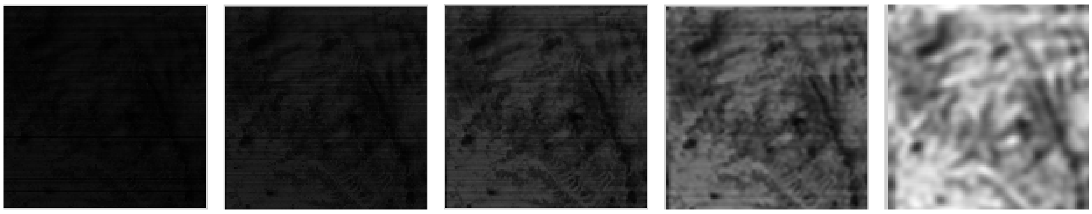
The algorithm in this paper can be described as consisting of the following four steps:

Step 1, depending on the characteristics of Fourier frequency spectrogram, the spatial distribution of stripe noise is detected. According to the distribution of stripe noise, such as horizontal or vertical distribution, threshold quantization is performed on the corresponding detail coefficients in step 3.

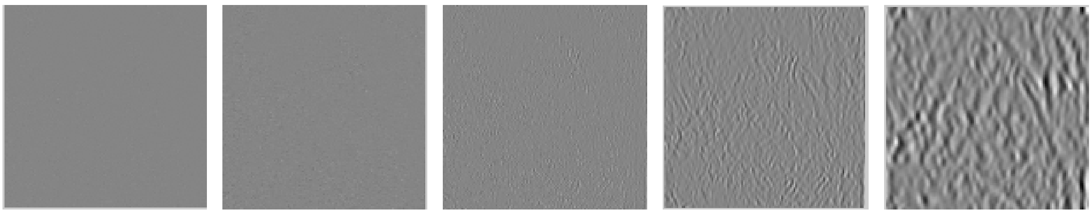
Step 2, stationary wavelet decomposition is performed on the images with stripe noise. After stationary wavelet transform, approximation coefficients, horizontal detail coefficients, vertical detail coefficients and diagonal detail coefficients are obtained. Before stationary wavelet decomposition, an appropriate wavelet base function and decomposition level should be selected. In general, the higher the wavelet decomposition level, the more detailed decomposed image is, and more effectively we can remove stripe noise during de-noising process. However, the growing wavelet decomposition level will increase computational complexity and time consumption. In the present work, wavelet base and wavelet decomposition level are respectively set to sym3 and five. Fig. 4 shows stationary wavelet decomposition results of Fig. 1 (d). Each row from left to right is respectively decomposition coefficient from the first floor to the fifth floor. As can be seen from Fig. 4, stripe noise mainly exists in horizontal detail coefficients after stationary wavelet decomposition. The reason for this phenomenon is that the distribution of stripe noise is horizontal. In addition, when the decomposition is already in the fifth floor, approximation coefficients do not contain stripe noise.

Step 3, threshold quantization is performed on the decomposition detail coefficients. Because all the images used in our experiments have horizontal stripe noise, we should choose an appropriate threshold to make threshold quantization for horizontal detail coefficients, whereas other coefficients remain constant. Fig. 5 is the results of Fig. 4 (b) after threshold quantization. It is observed that horizontal detail coefficients after threshold quantization do not include stripe noise.

Step 4, de-noised spatial domain image is reconstituted through processed coefficients. Approximation coefficients in the fifth floor and detail coefficients in each layer after threshold quantization are used to reconstruct de-noised image.


(a)The approximate coefficients


(b)The horizontal detail coefficients


(c)The vertical detail coefficients

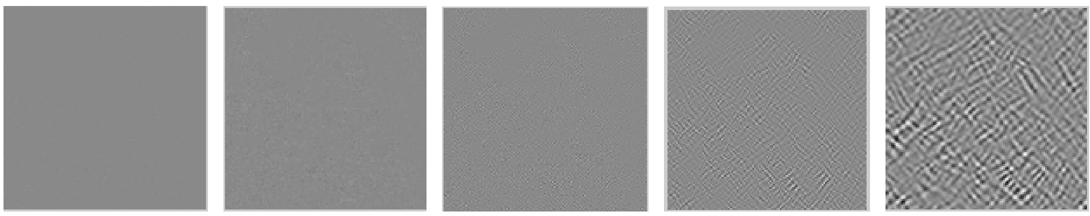

(d)The diagonal detail coefficients

Fig. 4. The decomposition coefficients after stationary wavelet transform.

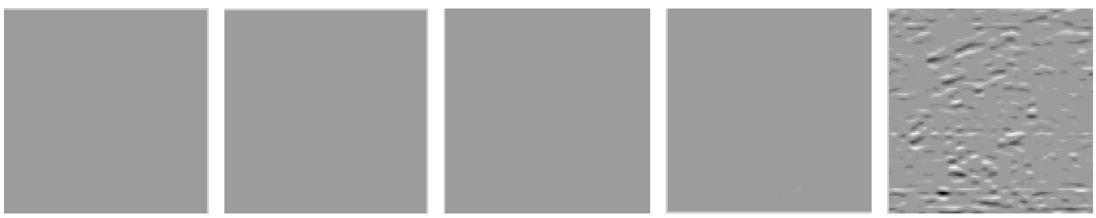


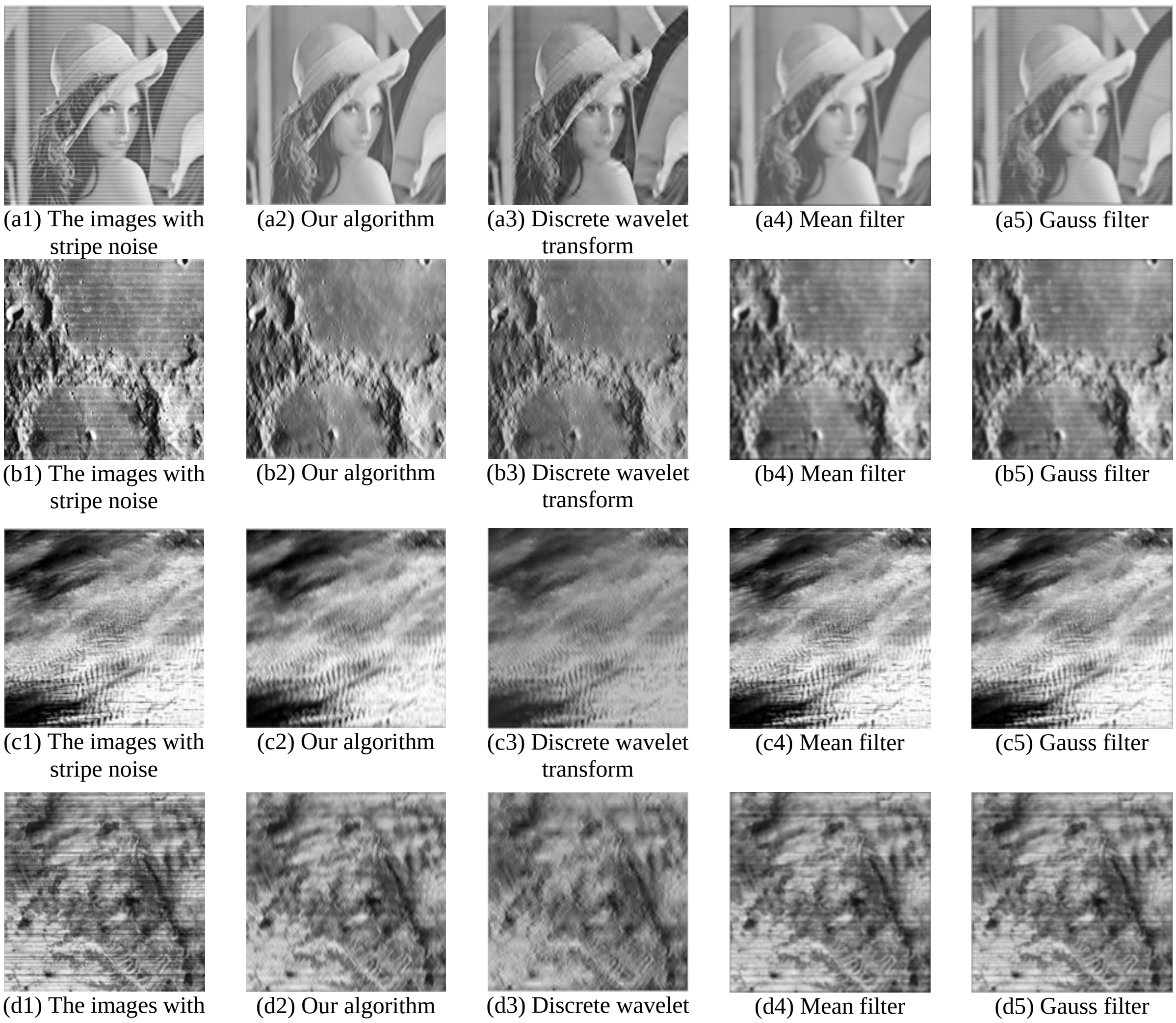
Fig. 5. The horizontal detail coefficients after threshold quantization.

5. Results and Analyses of Experiments

In order to verify the validity of the proposed algorithm, different images with horizontal stripe noise are tested in our experiments. Compared with discrete wavelet transform, mean filter and gauss filter, the new algorithm can remove stripe noise more efficiently while preserving original image details as much as possible.

As can be seen from Fig. 6 (a3), the algorithm based on discrete wavelet transform almost removes stripe noise completely in the Lena image. This is because the algorithm has carried out the detection of stripe noise distribution before de-noising, and meanwhile made threshold quantization for the corresponding detail coefficients which contain stripe noise. But because discrete wavelet transform do not have redundancy and shift-invariance, the details of the original image are not kept well. For example, the information of the hat's brim and the lips is lost substantially. In Fig. 6 (a4), one can see that mean filter can remove stripe noise effectively, but the details of the original image are also lost and the Lena image becomes blurred. Fig. 6 (a5) demonstrates that the Gauss filter cannot remove stripe noise completely, leaving some obvious remnants. Fig.6 (a2) shows the de-noising result using the newly proposed algorithm, which has better de-noising effect compared with the other methods used in this paper.

From Fig. 6 (b4) and (b5), (c4) and (c5), (d4) and (d5), it is seen that mean filter and Gauss filter cannot effectively remove stripe noise, leaving the remote sensing images with much of stripe noise after de-noising. From Fig. 6 (b3), (c3) and (d3), one can see that the algorithm based on discrete wavelet transform can remove stripe noise effectively, but the images after de-noising are duller as a whole. For example, the lower right corners of Fig. 6 (b3) and (c3) are darker than in the original image, while the illumination of Fig. 6 (b2) and (c2) is close to the original image. Furthermore, it is obvious that the texture information of Fig. 6 (d2) is clearer than that of Fig. 6 (d3).



(a1) The images with stripe noise; (a2) Our algorithm; (a3) Discrete wavelet transform; (a4) Mean filter; (a5) Gauss filter

(b1) The images with stripe noise; (b2) Our algorithm; (b3) Discrete wavelet transform; (b4) Mean filter; (b5) Gauss filter

(c1) The images with stripe noise; (c2) Our algorithm; (c3) Discrete wavelet transform; (c4) Mean filter; (c5) Gauss filter

(d1) The images with stripe noise; (d2) Our algorithm; (d3) Discrete wavelet transform; (d4) Mean filter; (d5) Gauss filter

Fig. 6. The experiment results.

6. Conclusions

We have presented a new algorithm based on Fourier transform and stationary wavelet transform to remove stripe noise. The new algorithm does not process approximation coefficients obtained through stationary wavelet decomposition, while processing detail coefficients depending on the detection of direction of the stripes before de-noising. For example, if the distribution of stripe noise is horizontal, threshold quantization is carried out for horizontal detail coefficients while other detail coefficients remains unchanged. Compared with discrete wavelet transform, mean filter and gauss filter, the new algorithm can both remove stripe noise effectively and preserve the details of original image. In the cases where the distribution of the stripe noise is horizontal, vertical or diagonal, the present work has achieved some important new results.

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