AN INSITU SINGLE-POINTED WAVELET-BASED METHOD FOR NOISE REDUCTION IN SAR IMAGES

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ABSTRACT:

Speckle noise caused by interference of electromagnetic waves complicates Synthetic aperture radar (SAR) images to be interpreted and further practical application, therefore reducing speckle noise and preserving more detailed information are indispensable tasks in pre-processing. In this paper, a new insitu single-pointed (ISPW) method based on wavelet decomposition to several scales to suppress speckle noise was introduced. On the basis that pixels in log-transformed images are mutually independent, we operate insitu operations on wavelet coefficients in both approximate and detailed parts in each scale according to distribution of approximate component in each wavelet decomposition scale, while not affecting others' in order to remove more speckle noise as well as preserve more original edge information. Several evaluation criteria are applied to examine the performance of this ISPW method. Results of experiments show that ISPW method can give a better visual quality and obtain a higher signal-to-noise ratio (SNR), peak signal-to-noise ratio (PSNR) and edge preserving ability (EPA) as well.

1. INTRODUCTION

Synthetic aperture radar (SAR) plays an increasingly important role in offering information of earth's surface and they are now widely used in various implementations such as resource monitoring, navigation and positioning and military command. However, the coherent integration brings speckle noise into SAR images during the process of receiving signals from targets towards which space borne or airborne platform sends electromagnetic waves (Goodman, 1976); and the introduction of speckle noise makes it difficult for people to interpret SAR images to practical purpose. Hence, it is critical to remove speckle noise from SAR images in pre-processing steps.

Such many spatial-domain filters have been proposed for suppressing speckle noise as Lee, Frost and so forth (Lee, 1980; Frost, 1982), however these approaches are greatly dependent on size and orientation of their local windows. Usage of neighbourhood pixel values weakens the object signals and detailed edge information, the focus of surveying, mapping and orientation. Recently, multi-scale wavelet transform and threshold techniques are developed in removing speckle noise from image signals. According to characteristic of wavelet coefficient, many authors suggested various methods to select effective threshold, and universal threshold (Donoho and Johnstone, 1994), GCV threshold(Jansen, Malfait and Bultheel, 1997) and BayesShrink threshold (Chang, Yu and Vetterli, 2000) are three typical thresholds. It has been shown that compared with spatial-domain filters, wavelet threshold can operate a better performance in reducing speckle noise (Gagnon and Jouan, 1997). However, based on statistical estimation and global probability, these wavelet threshold methods can still not provide a better result in preserving more edge information.

On the basis of these discussions, it is necessary to propose a new approach to suppress speckle noise in its own position while not affecting neighbourhood pixel information to reduce the loss of edge. In this paper, a new insitu single-pointed wavelet-based (ISPW) method, that employs distribution of approximate part of wavelet coefficients to locally operate on both approximate and detailed components, is proposed for denoising speckle noise in SAR images. This approach eliminates speckle noise locally while not involving their neighbourhood information. The performance of proposed ISPW method using several statistical values is compared to that of some of the existing techniques.

2. PROPOSED METHOD FOR DENOISING SAR IMAGES

2.1 Basis of proposed method

Let y(k, l) denote the intensity of (k, l)th pixel in a SAR image, s(k, l) the noise-free image pixel which we wish to recover from y(k, l), and n(k, l) the multiplicative speckle component. Assuming the speckle to be fully developed, y(k, l) is expressed as (M. I. H. Bhuiyan, M. O. Ahmad and M. N. S. Swamy, 2007):

$$y(k, l)= s(k, l)* n(k, l) \quad (1)$$

With the log-transformation, (1) becomes

$$Y(k,l)=X(k,l)+N(k,l) \quad (2)$$

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Where Y=ln(y), X=ln(s) and N=ln(n). Log-transformed SAR image makes multiplicative speckle noise additive. Thus, multiplicative correlations between pixels in original images are non-existent among that of log-transformed images, in other words, pixels of log-transformed images are mutually independent. It makes less difficult to separate and extract SAR speckle noise from images.

On the basis of this mutually independent characteristic of log-transformed SAR images, we propose a new insitu single-pointed wavelet-based (ISPW) algorithm to reduce speckle noise locally, not affecting features of other useful signals. The fundamental principle of ISPW method is to discern speckle noises according to features of noise independent impulse response, then to specifically identify speckle noise and to reduce speckle noise in located positions. It can preserve image edge information in maximal extent and avoid such disadvantages of conventional denoising algorithms as over-filtering resulting in a loss of a great deal of point-target electromagnetic scattering characteristics, so it is undoubtedly benefit for computation of stereo-imaging.

Speckle noise belongs to single-point impulse and its response bands are broad which approximately don't attenuate in frequency domain; this means speckle noise represent fairly similar characteristic in both high and low frequency. Conventional FIR filters are almost ineffective in suppressing speckle noise because of inability to separate different frequency bands; while wavelet decomposition can achieve such separation. The discrete wavelet transform (DWT) of a two-dimensional image to a level J obtains an approximation subband cA_J, containing the low-frequency components of images, and three detailed subbands cH_J, cV_J, cD_J, high-frequency portions of images including horizontal, vertical and diagonal features in the images (Mallat, 1989). Distribution of cA_J is used as source of discerning and locating speckle noise, then cA_J, cH_J, cV_J, cD_J of these located positions should be operated to appropriate values instantaneously in each wavelet scale in that separated impulse responses are one-to-one correspondences in each frequency band.

Furthermore, an effective wavelet base plays an indispensable role in detecting and locating speckle noise. Different wavelet bases fit for monitoring and detecting different types of signals, thus a wavelet base that is more sensitive to single-point impulse than that of others is obviously more helpful in reducing speckle noise.

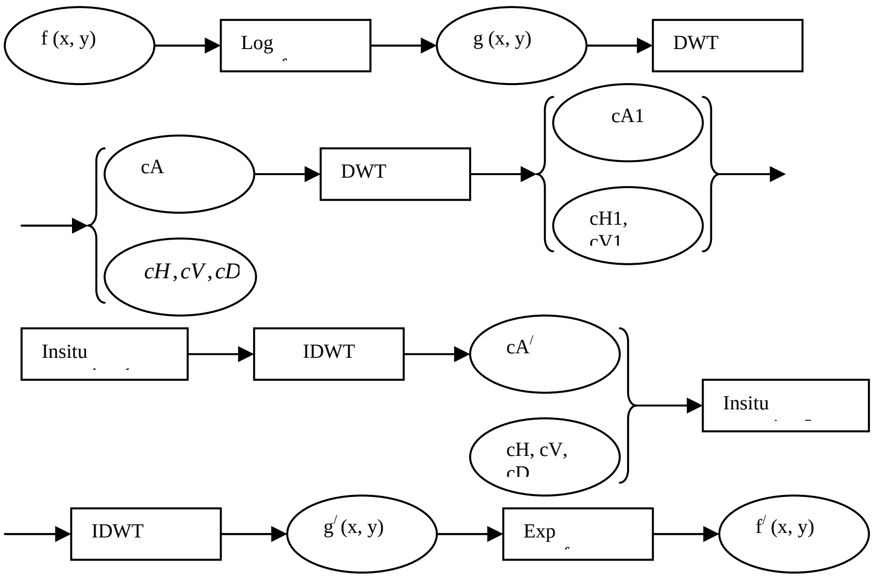


Figure1. Fundamental flow of proposed method

2.2 Method specifications

Fundamental flow of proposed method for denoising speckle noise in a SAR image is shown in Figure 1. Detailed processing steps are described as follows:

1) Carry out the logarithmic transform of the original SAR image f(x, y).
2) Apply discrete wavelet transform on the log-transformed image g(x, y), obtaining wavelet coefficient of first scale: approximate information cA and detailed information in horizontal, vertical and diagonal directions cH, cV and cD.
3) Employ discrete wavelet transform on cA, acquiring wavelet coefficient of the second scale: approximate information cA1 and detailed information in horizontal, vertical and diagonal directions cH1, cV1 and cD1.
4) Perform insitu operation 1. According to wavelet coefficient distribution of cA1, choose appropriate parameters p, q, m, and n to apply insitu operation on cA1, cH1, cV1 and cD1.
   If cA1(i, j)<-p*var(cA1),
   then cA1(i, j)=-p*var(cA1), cH1(i, j)=m, cV1(i, j)=m, cD1(i, j)=m;
   If cA1(i, j)>q*var(cA1),
   then cA1(i, j)=q*var(cA1), cH1(i, j)=n, cV1(i, j)=n, cD1(i, j)=n.
5) Reconstruct the wavelet coefficient experienced insitu operation 1 in step 4 to the first scale, obtaining new wavelet coefficient of approximate component in the first scale, namely, $cA^{/}$.
6) Perform insitu operation 2. According to wavelet coefficient distribution of $cA^{/}$, choose appropriate

parameters k and r to apply insitu operation on $cA^{/}$, cH, cV and cD.
If $cA^{/}(i, j)<k$,
then cH(i, j)=k, cV(i, j)=k, cD(i, j)=k;
If (cH, cV, cD)(i, j)>r*var(cH, cV, cD),
then (cH, cV, cD)(i, j)=r*var(cH, cV, cD);
If (cH, cV, cD)(i, j)<-r*var(cH, cV, cD),
then (cH, cV, cD)(i, j)=-r*var(cH, cV, cD).

7) Apply the inverse discrete wavelet transform of the wavelet coefficient achieved in step 6.
8) Carry out exponential transform of the values $g^{/}(x, y)$ obtained in step 7 to get the denoised image $f^{/}(x, y)$.

3. EXPERIMENTAL RESULTS

3.1 Data Description

Two SAR images covering Hulu Island area located in Liaoning province in China are used in our experiments. Also, two SPOT5 images of the same latitude and longitude are provided to do a comparison. More detailed information about these two SAR images and optical images can be seen in Table1.

Satellite	Radarsat2
Time of first data	Jan, 15th, 2007
Latitude at Image center (degree)	40.7911434
Longitude at image center (degree)	120.5331714
Incidence Angle (degree)	44.716
Number of azimuth looks	1.0000000
Number of range looks	1.0000000
Line spacing (m)	6.2500000
Pixel spacing (m)	6.2500000

Satellite	SPOT5
Time	Sep, 17th, 2006
Latitude at Image center (degree)	40.840054
Longitude at image center (degree)	120.481283
Incidence Angle (degree)	13.885192
Resolution (m)	10.000000
Instrument	HRG

Table1. Specific information about experimental SAR and optical images

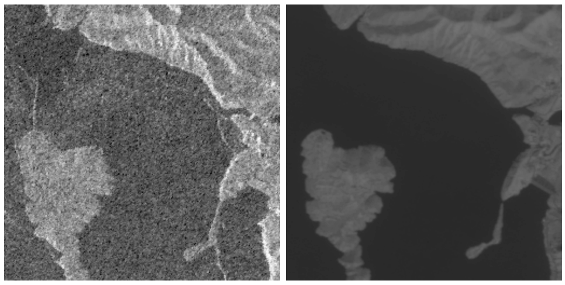
3.2 Experiment Ⅰ

Several filters are employed on the SAR image, including: median, Lee, Lee-Sigma, Frost, Gamma-MAP, Wiener, wavelet threshold and ISPW method. Table2 lists all filter parameters used in the paper. These selected parameters do not imply the filters having been turned to the optimal. Instead the selection enables all filters to reduce speckle to an approximately similar level, so that analysis and comparisons can be fairly performed (Y. Dong, A.K. Milne and B. C. Froster, 2001).

Filters	Parameters
Median	Window size: 3*3
Lee	Window size: 3*3, Coefficient of Variation: 0.2
Lee-Sigma	Window size: 3*3, Coefficient of Variation: 0.2
Frost	Window size: 3*3, Coefficient of Variation: 0.2
Gamma-MAP	Window size: 3*3, Coefficient of Variation: 0.2
Wiener	Window size: 3*3
Wavelet threshold	Threshold type: hard Threshold method: Section (Anurat Ingun, 1996)

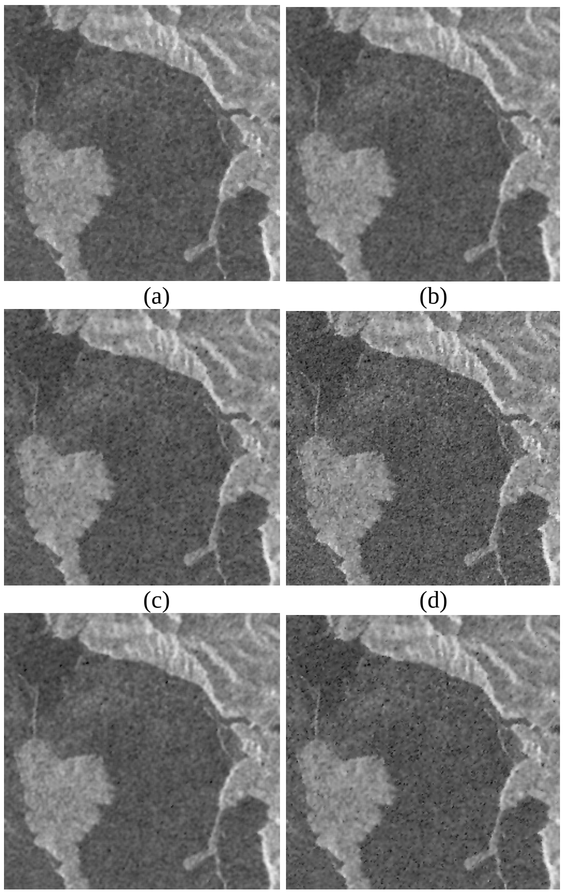
Table2. Filter parameters used in the paper

Original SAR image and its corresponding SPOT5 image are shown in Figure2, denoised images of different filters are shown in Figure3.

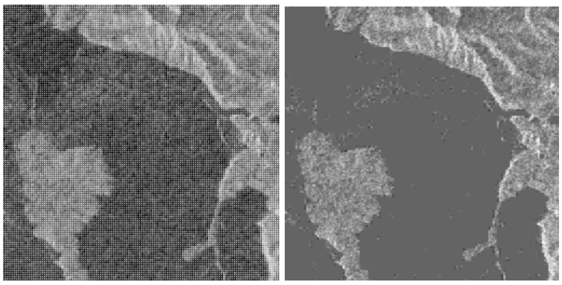


(a) (b)

Figure2. Original SAR image (a) and corresponding SPOT5 image (b)



(a) (b) (c) (d) (e) (f)



(g) (h)

Figure3. Result of different filters
(a) Median, (b) Lee, (c) Lee-Sigma, (d) Frost, (e) Gamma-MAP, (f) Wiener, (g) wavelet threshold, (h) ISPW

In order to comprehensively evaluate and analysis the performance of filtering results in Figure3, aside from visual quality five statistical values are considered. They are radiometric resolution (RR), effective number of looks (ENL) (Wakabayashi H and Arai K, 1996), signal-to-noise ratio (SNR), peak signal-to-noise ratio (PSNR) and edge preserving ability (EPA). Table3 shows statistical results of filtering results in Figure3.

In view of visual quality, all kinds of filters can suppress speckle noise to some extent, and instantaneously blur edge information of original SAR image to certain degree as well. Among these images, proposed method owns the best visual quality. It preserves more edge information while removes more speckle noise than others as well, especially in river section, which reflects more distinctly and clearly. In contrast, Frost filter gives the worst visual quality for it removes only a few number of speckle noise, making denoised image the most difficult to discern.

	RR	ENL	SNR	PSNR	EPA
Original	1.4689	1.5920	---	---	---
Median	1.2537	2.2796	14.2822	22.7056	0.4241
Lee	1.2384	2.3786	15.0376	23.4610	0.4035
Lee-Sigma	1.2840	2.2393	15.3985	23.8219	0.4567
Frost	1.3656	1.9578	21.0488	29.4722	0.7286
Gamma-MAP	1.2322	2.4039	14.7218	23.1452	0.3864
Wavelet threshold	2.5968	0.5030	2.3372	10.7606	0.2755
Wiener	1.2774	2.2910	15.2190	23.6425	0.4438
ISPW	1.2086	2.0171	15.7170	24.1404	0.6103

Table3. Statistical result of filtering images

Radiometric resolution (RR) is to measure scattering electromagnetic features of targets; and the smaller radiation resolution value is, the more effectively it removes speckle noise. Table3 illustrates ISPW provides smaller value of RR in comparison to the other methods, indicating a better ability to reflect object scattering electromagnetic characteristic.

Effective number of looks (ENL) reveals the ability to suppress speckle noise, hence the bigger ENL is, the stronger ability it removes speckle noise. It can be seen from Table3 that compared to other filters ENL value of ISPW is not optimistic, which remains deserve further improvement.

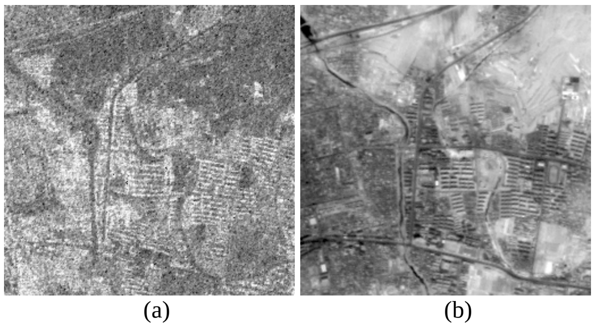
Signal-to-noise ratio (SNR) and peak signal-to-noise ratio (PSNR) are the same sort of criteria to assess denoising result. The bigger SNR and PSNR values are, the more useful information image contains, and the better the algorithm suppresses speckle noise. It can be observed from Table3 that proposed ISPW method gives bigger value of SNR and PSNR than those of other methods except Frost, however denoised images of Frost filter is obviously worse than that using ISPW method. The reason for this phenomenon is that Frost filter removes comparatively less noise, making a smaller denominator in SNR and PSNR expression and inadequately improving SNR and PSNR values.

Edge preserving ability (EPA) represents ability to preserve edge information of original images. The closer EPA approximates 1, the better denoised images preserve edge information of original ones. Tables3 reveals that EPA value of ISPW is larger that that of others' except Frost, however, EPA value of Frost filter inaccurately indicates its edge-preserving ability, because Frost filter leaves more noise unremoved from original image including information mistakenly detected as edge, thus EPA value is inappropriately improved.

From above analysis, statistical values reflect some but not all characteristics of denoised results. Thus it is fairly necessary to firstly consider visual quality into comprehensive evaluation.

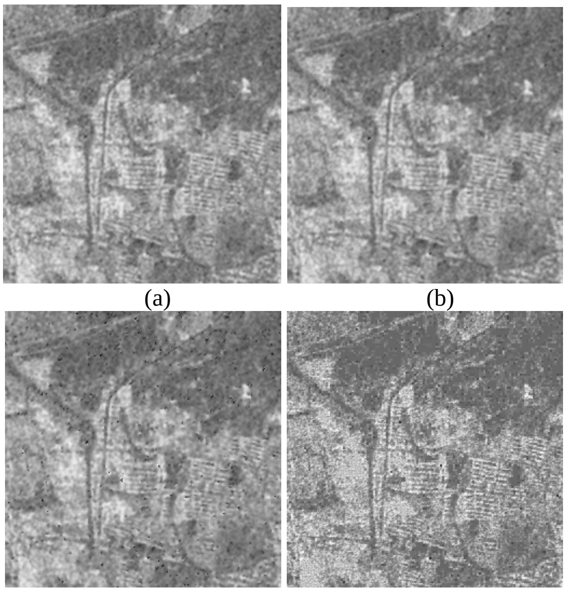
3.3 Experiment Ⅱ

We choose four filters, which generally obtains much better results in experiment Ⅰ in both visual quality and statistical values aspects, to operate on another SAR image, containing different sort of objects to further evaluate performance of proposed ISPW method. Original image and corresponding SPOT5 image are shown in Figure4, denoised images of different filters and their statistical results are shown in Figure5 and Table4 respectively.



(a) (b)

Figure4. Original SAR image (a) and corresponding SPOT5 image (b)



(a) (b)

(c) (d)

Figure5. Result of selected filters on another SAR image
(a) Lee, (b) Gamma-MAP, (c) Wiener, (d) ISPW

The results of this experiment show that ISPW method achieved similar results as that of experiment Ⅰ except RR values. Denoised image of ISPW method gives the best visual quality as well as the highest SNR, PSNR and EPA values in comparison of the rest filters. However, ENL is still not optimistic in this experiment, and RR cannot retain a good result as foregoing experiment. According to definition of radiation resolution, it is proportional to ratio of deviation to mean, therefore, it can be easily compensated by grey linear or non-linear transform.

4. CONCLUSIONS

In this paper, a new technique to reduce speckle noise in SAR images has been proposed. On the basis that pixels of log-transformed SAR images are mutually independent, this insitu single-pointed wavelet-based approach makes use of approximate component information of wavelet coefficient in each scale to deal with approximate and detail part in corresponding scale in order to suppress speckle noise locally and not affect other useful information. A generally comprehensive series of evaluation criteria is applied to analyze the performance of this method. Experiment results show that this method gives a comparatively better image with more detailed edge information and more clean objects.

	RR	ENL	SNR	PSNR	EPA
Original	1.5015	1.3793	---	---	---
Lee	1.2056	2.2287	14.1288	21.1549	0.3904
Gamma-MAP	1.1930	2.2831	13.5733	20.5993	0.3690
Wiener	1.2447	2.1147	14.1557	21.1817	0.4325
ISPW	1.3307	1.6650	16.0485	23.0745	0.6667

Table4. Statistical result of selected filters on another SAR image

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