Applied Mechanics and Materials Vols. 333-335 (2013) pp 916-919
Online available since 2013/Jul/15 at www.scientific.net
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doi:10.4028/www.scientific.net/AMM.333-335.916

SAR Image Denoising Based on Wavelet Packet and Median Filter

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Keywords: Denoising ;SAR Image ; Wavelet; Wavelet Packet ; Median Filter.

Abstract. In this study a novel image processing approach is proposed to improve the denoising in SAR images based on wavelet packet and median filter, Median filter is adopted to remove noise in the wavelet packet domain. At first, the process of the novel is introduced in detail .At last, by adding some simulated noise in the SAR image, the performance of the proposed approach is shown and compared with other filter algorithms in terms of PSNR.

Introduction

Synthetic aperture radar systems are all-weather, night and day, imaging systems. Automatic interpretation of information in SAR images is very difficult because SAR images are corrupted by speckle noise that arises from an imaging device and strongly hinders data interpretation. As a consequence, detecting objects and regions of interest in SAR images may be a severe challenge even for an expert interpreter, while automatic algorithms devoted to the same tasks are just not reliable enough for many applications [1]. For this reason, in recent years there has been a growing interest in SAR image denoising motivated also by the appearance of powerful techniques [2].

The wavelet packet transform (WPT) describes a rich library of bases (wavelet packets) with an arbitrary time-frequency resolution for overcoming the drawback in the traditional wavelet transform [3]. By applying linear superposition of wavelets, desirable properties of orthogonally, smoothness and localization of the parent wavelets are retained. Recently, the practical importance of WPT applications has led to great research interest and measurable advances in various fields such as image processing [4], pattern recognition [5]. In most cases, images denoising performance based on the wavelet packet transform are more satisfactory than denoising based on wavelet transform. In our study, a novel image processing approach is proposed to improve the denoising in SAR images based on wavelet packet and median filter.

Wavelet Packet Transform

If the function Ψ(t)∈L(R) satisfies the permissibility condition

$$C_\Psi = \int_{-\infty}^{\infty} \frac{|\hat{\Psi}(\omega)|^2}{\omega} d\omega < +\infty \tag{1}$$

Where $\hat{\Psi}(\omega)$ is the Fourier Transform of Ψ(t), thenΨ(t) is called a wavelet mother function. The wavelet function $\Psi_{a,b} = a^{-1/2}\Psi(\frac{t-b}{a})$ is derived from a mother functionΨ(t) for various scale a and location b. For any time signal $f(t) \in L^2(R)$ the wavelet transform of the time signal f(t) is defined as inner product of the signal and the wavelet function:

$$WT_f(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} f(t)\Psi^*(\frac{t-b}{a})dt = < f, \Psi_{a,b} > \tag{2}$$

In the frequency domain, we have

$$WT_f(a,b) = \frac{1}{2\pi} < \hat{f}, \hat{\Psi}_{a,b} > = \frac{\sqrt{a}}{2\pi} \int_{-\infty}^{\infty} \hat{f}(\omega) e^{ibw} \Psi^*(a\omega) d\omega \tag{3}$$

Where Ψ* is the conjugate of Ψ .

If the scale a= 2j, j∈Z, the corresponding wavelet transform is called dyadic wavelet transform. In Mallat's fast algorithm, the discrete dyadic wavelet transform is

$$\begin{cases} \varphi(t) = \sum_{k \in z} g(k)\varphi(2t-k) \\ \phi(t) = \sum_{k \in z} h(k)\varphi(2t-k) \end{cases} \tag{4}$$

Where h(k) and g(k) are a pair of complementary conjugate filters. The algorithm is called multi-resolution analysis. $\varphi(t)$ and $\phi(t)$ are approximation coefficient and detailed coefficient of the signal, respectively.

Wavelet analysis does not involve the decomposition of signal in the detail, but wavelet packet analysis, the extension of wavelet analysis, will decompose not only the approximate but also the detail of the signal. Wavelet packet decomposition provides the finer analysis:

$$\begin{cases} u_{2n}(t) = \sqrt{2}\sum_{k \in z} h_k(t)u_n(2t-k) \\ u_{2n+1}(t) = \sqrt{2}\sum_{k \in z} g_k(t)u_n(2t-k) \end{cases} \tag{5}$$

Wavelet packet decomposes the original signal that is non-stationary or stationary into independent frequency bands. There is no redundant information in the decomposed frequency bands.

Median filter

The basic principle of the Median filter is to substitute the Median value of a sliding window of a certain size with the midmost point in the window. Suppose x1,x2,…,xn is a sequence in a sliding window and the sequence is arranged in ascending order, i.e. x1≤x2≤…≤xn. The Median value can be written as

$$y = \begin{cases} \frac{1}{2}(x_{n/2} + x_{n/2+1}), if\ n\ is\ even \\ x_{(n+1)/2}, if\ n\ is\ odd \end{cases} \tag{6}$$

The Median filter can remove impulse noise, especially that whose width is less than half of the sliding window. The smoothness of a signal is relevant to the sliding window size. When the window is wider the denoised signal is smoother. Too wide of a window may result in over smoothing.

The process of SAR Image Denoising Based on wavelet packet and median filter

The method proposed in our paper consists of a wavelet packet and median filter. First, by employing the WPT in the spatial frequency domain, the real and imaginary parts of SAR image are decomposed into the wavelet packet coefficients. Second, for these coefficients, median filtering is adopted to remove the noise. Then, we do an inversion of the wavelet packet and remove noise again by using wavelet packet soft-thresholding.

Assume s(x) represents the original image information, f(x) is the noise information and n(x) denotes the noise component. Then

$$s(x)= f(x) + n(x) \tag{7}$$

The noise information f(x) corresponds to the low frequency of s(x) and represents the main outline of information. The background noise n(x) corresponds to the high frequency and represents the detail. Therefore, the wavelet packet decomposition coefficients of the background noise are concentrate on high frequency coefficients. Based on this fact, the algorithm of removing SAR image noise can be described step by step as follows:

(1) Image wavelet decomposition

Choose a wavelet base function and ascertain the wavelet decomposition's scale N. Then decompose the signal in N scales by wavelet packet.

(2) Wavelet packet coefficients Median Filter

Adopt the Median filter to remove noise in the WPT domain. For N-scales wavelet packet decomposition, we use the Median filter with different local window sizes to reduce noise in wavelet packet coefficients.

(3) Inverse wavelet packet transform and wavelet packet denoising

Inverse wavelet packet is fulfilled based on its low frequency and its quantization coefficients. The wavelet packet soft-threshold is used to remove noise again.

In order to determine the initial threshold value, the noise variance σ2 needs to be estimated first. It is estimated from the corresponding QCWPT coefficients, by the robust median estimator [6]

$$\hat{\sigma} = \frac{Median(|c_{1,k}|)}{0.6745} \tag{8}$$

Where c1,k are the high frequency coefficients of wavelet packet decomposition in first scale, k=1,2,3,4,…and 0.6745 is the coefficient of median estimator.

SAR Image denoising experiment and performance comparison

In this section, Peak Signal to Noise Ratio (PSNR) is used to evaluate the performance of the denoising methods. In many cases speckle noise exists in images. An original SAR image was used as a test image in figure 1. It was degraded by speckle noise 0.1 in figure 2. Median filter with 3×3 local window size, wavelet and wavelet packet representations at three-scale, and "Symmlet" with eight vanishing moments (Symmlet 8) were used to conduct the image denoising experiments. The results are listed in figures 3 through 6.


Fig.1 Original image

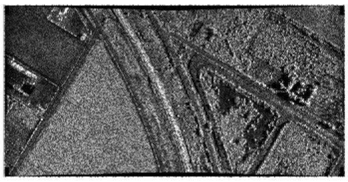
Fig.2 Speckle image

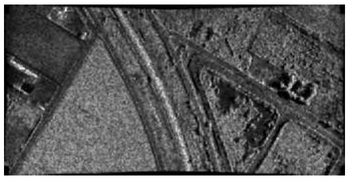
Fig.3 Median filter denoising

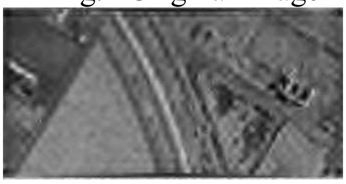
Fig.4 Wavelet denoising

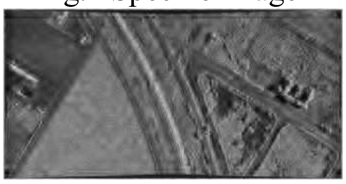
Fig.5 Wavelet packet denoising

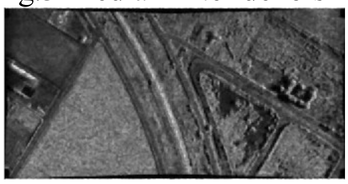
Fig.6 Our method denoising

We can see from figures 3 through 6, that t our method obtains the best result compared to the other methods.The results for varying speckle noise, local window size, and scale are summarized in tables 1 through 4.

Table 1 Median filter denoise result based on different local window size

size	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2
	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR
3×3	23.59	22.07	20.99	19.99	19.23	18.71	18.13	17.70	17.24	16.81
5×5	22.51	21.81	21.12	20.72	20.19	19.72	19.38	19.03	18.72	18.41
7×7	21.72	21.21	20.71	20.37	20.07	19.72	19.46	19.13	18.94	18.66

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Table 2 Wavelet denoise result based on different scales

scale	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2
	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR
2	22.16	20.61	19.58	18.71	18.04	17.46	16.98	16.52	16.10	15.75
3	21.44	20.05	19.08	18.31	17.71	17.21	16.73	16.30	15.94	15.63
4	21.24	19.80	18.80	18.081	17.44	16.97	16.51	16.13	15.74	15.44

Table 3 Wavelet packet denoise result based on different scales

scale	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2
	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR
2	23.84	21.63	20.20	19.22	18.37	17.67	17.12	16.65	16.22	15.78
3	23.48	21.31	20.13	19.14	18.43	17.74	17.19	16.72	16.34	15.93
4	23.25	21.22	19.99	19.05	18.32	17.71	17.16	16.68	16.28	15.87

Table 4 Our method denoise result based on different scales and local window size

scale	size	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2
		PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR	PSNR
2	3*3	23.71	22.74	21.91	21.25	20.72	20.16	19.78	19.34	19.01	18.65
	5*5	22.44	21.89	21.49	21.09	20.78	20.34	20.18	19.82	19.58	19.43
	7*7	21.55	21.17	20.83	20.52	20.24	19.95	19.76	19.49	19.29	18.98
3	3*3	23.74	22.77	22.00	21.25	20.80	20.28	19.82	19.54	19.19	18.83
	5*5	22.40	21.92	21.45	21.09	20.74	20.42	20.19	19.94	19.58	19.41
	7*7	21.55	21.15	20.81	20.49	20.24	19.99	19.71	19.53	19.27	19.12
4	3*3	23.75	22.74	21.98	21.40	20.90	20.33	19.97	19.55	19.22	18.89
	5*5	22.42	21.90	21.47	21.09	20.79	20.45	20.21	19.96	19.69	19.41
	7*7	21.57	21.17	20.80	20.48	20.20	20.01	19.77	19.47	19.27	19.13

By comparing tables 1 through 4, we can conclude that:

(1)When the speckle noise is low, the Wavelet packet has the best performance compared to the other methods. The next best is the our method.(2)When the speckle noise is high our method has the best performance. The next is the Median filter method. (3) During our method, different Wavelet packet scales and Median filter local window sizes can get different denoise result. So we can change the scales and window sizes according to the noise.

Summary

Removing speckle has become an essential step in SAR image analysis and improving image quality. In this study we introduced several common denoising methods, such as Median filter, wavelet transform and wavelet packet transform. A novel image processing approach is proposed to improve the denoising in SAR images based on wavelet packet and median filter. The experiments have demonstrated that our approach had a better image denoising effect.

Acknowledgements

This work is supported by the Natural Science Foundation of Hunan Province(12JJ4058),Key Construction Disciplines of the Hunan Province during the Twelfth Five-Year Plan Period,and Hengyang Normal University Science Foundation Project(11B44, 11A29)

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10.4028/www.scientific.net/AMM.333-335

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10.4028/www.scientific.net/AMM.333-335.916