An Optimal SAR Speckle Filter

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Abstract: In the past 20 years or so, numerous methods to reduce speckle in SAR images have been proposed. The primary goal of these methods is to reduce speckle without destroying resolution and smearing edge information. But the experiments indicate that there is always a kind of tradeoff between smoothing out speckle and preserving edge information. In this paper, an optimal SAR speckle filter is developed It can effectively smooth out speckle while preserve edge information.

Key word: SAR, Speckle, Filter

Ⅰ. Introduction

A speckle pattern formed in polarized monochromatic microwave may be regarded as resulting from a classical random walk in the complex plane (Goodman 1976). Speckle in synthetic aperture radar (SAR) images disturbs SAR image calibration, validation, and interpretation. Thus in most cases of practical interest, reducing speckle is a goal towards which we aspire (Shi and Fung 1994).

In the past 20 years or so, numerous methods to reduce speckle have been proposed. Basically, these methods can be divided into two categories (Lee 1986). The first category is multi-look processing, which is to average several looks obtained from the same scene. Multi-look processing is equivalent to applying a low-pass filter to the images. Although effective and simple, it not only suppresses the speckle but also degrades image spatial resolution and smears the edge information at the same time (Shi and Fung 1994). Techniques in the second category smooth speckle based on digital image processing after the images have been formed. A number of filters in the second category have been proposed to reduce speckle based on speckle models, such as the Lee (Lee 1980), the Kuan (Kuan *et al.* 1985), the Frost (Frost *et al.* 1982), the modified Lee and modified Frost (Lopes *et al.* 1990), and filters based on the Maximum A Posteriori (MAP) probability (Kuan *et al.* 1987). Meanwhile other filters not based on speckle models, such as median filter, geometric filter (Crimmins 1985), and wavelet transform (Dong *et al.* 1998, 2001, Fukuda and Hirosawa 1998) filter have also been applied for reducing speckle. The primary goal of these methods is to reduce speckle without destroying resolution and edge information. Both suppression of speckle in a uniform area and preservation of edges cannot really be satisfied simultaneously. Therefore, Several quantitative criteria such as standard deviation reduction, mean preservation, and edge preservation have been proposed to evaluate SAR images speckle filters. The results of comparison of speckle filters indicate that no filter can satisfy with these criteria simultaneously. In terms of mean preservation, the most filters can effectively preserve the mean of images. The problem of these filters is that these filters cannot reduce speckle while preserve edge information.

In this paper, a method to reduce speckle in SAR images is developed. It is an optimal filter in terms of the visual appearance, mean preservation, the standard deviation reduction, and edge preservation.

II. Method

The presented method is developed from the method proposed by Han *et a l*(2002). The method cannot effectively reduce speckle as the other filters. In this paper, the method is enhanced in speckle suppression.

2.1Detecting edge orientation

First step of this method is to detect edge direction. The definition of edge in an image is an area with sharp intensity variations. Thus we will detect grad of the area with sharp intensity variations. Over the past few years, a number of edge detectors have been proposed. In this paper, we use an edge detector to detect the local edge orientations, which are the directions along the edges. For a pixel p(i,j) and the pixels used for local edge detection as shown in figure 1, to detect the orientations of edge compute:

T[0][0]=(p(i-1,j)+p(i,j)+p(i+1,j))/3

T[0][1]=(p(i-1,j-1)+p(i,j-1)+p(i+1,j-1))/3

T[0][2]=(p(i-1,j+1)+p(i,j+1)+p(i+1,j+1))/3

Let T0=max{|T[0][0]-T[0][1]|, |T[0][0]-T[0][2]|}, then

T[1][0]=(p(i,j-1)+p(i,j)+p(i,j+1))/3

T[1][1]=(p(i-1,j-1)+p(i-1,j)+p(i-1,j+1))/3

T[1][2]=(p(i+1,j-1)+p(i+1,j)+p(i+1,j+1))/3

	p(i-1,j-2)		p(i+1,j-2)	
p(i-2,j-1)	p(i-1,j-1)	p(i,j-1)	p(i+1,j-1)	p(i+2,j-1)
	p(i-1,j)	p(i,j)	p(i+1,j)	
p(i-2,j+1)	p(i-1,j+1)	p(i,j+1)	p(i+1,j+1)	p(i+2,j+1)
	p(i-1,j+2)		p(i+1,j+2)	

Figure 1. Illustration of pixels used for local edge orientations detection

Let T1=max{|T[1][0]-T[1][1]|, |T[1][0]-T[1][2]|} , then

T[2][0]=(p(i-1,j+1)+p(i,j)+p(i+1,j-1))/3

T[2][1]=(p(i-2,j+1)+p(i-1,j)+ p(i,j-1)+p(i+1,j-2))/4

T[2][2]=(p(i-1,j+2)+p(i,j+1)+p(i+1,j)+p(i+2,j-1))/4

Let T2=max{|T[2][0]-T[2][1]|, |T[2][0]-T[2][2]|} , then

T[3][0]=(p(i-1,j-1)+p(i,j)+p(i+1,j+1))/3

T[3][1]=(p(i-1,j-2)+p(i,j-1)+p(i+1,j)+p(i+2,j+1))/4

T[3][2]=(p(i-2,j-1)+p(i-1,j)+p(i,j+1)+p(i+1,j+2))/4

Let T3=max{|T[3][0]-T[3][1]|, |T[3][0]-T[3][2]|}.

Let T=max{T0, T1, T2, T3}. If T=T0, the edge direction is horizontal. If T=T1, the edge direction is vertical. If T=T2, the edge direction is right diagonal. And if T=T3, the edge direction is left diagonal. To eliminate noise influence, we set a threshold, which is the 60 percent of the pixel mean in figure 1. If T is greater than the threshold, there is an edge. If T is less than the threshold, there is no edge. It is very difficult to set a threshold so that there is small probability of marking noise edges while retaining high sensitivity (Canny 1986). This threshold is obtained based on our experience.

2.2 Data smoothing

A. One-Dimensional Data Smoothing

There are numerous methods of data smoothing. We selected Empirical Mode Decomposition (EMD) (Huang *et al.* 1998) to smooth SAR image data. The essence of the EMD is to identify the intrinsic oscillatory modes by their characteristic time scales in the data empirically, and then decompose the data accordingly. For a one-dimensional signal X(t), performing the EMD, we can obtain:

$$X(t) = \sum_{i=1}^{n} c_i(t) + r(t)$$

The first mode $c_1(t)$ is the short scale component, the nth mode $c_n(t)$ is the large scale component, and r(t) is the residue. From a traditional viewpoint, $c_1(t)$ is equivalent to the high frequency component, and $c_n(t)$ is equivalent to the low frequency component. Since EMD decomposes data set into different modes based on different scales, data smoothing can then be obtained in designated scales. That is

$$X(t)-\sum_{i=1}^{n1} c_i(t)=S(t)$$

where, S(t) is the smoothed data. To illustrate the smoothing result, a line of SAR image pixels (pixel values between 0 and 255) is smoothed. The original data is shown as the dotted line in figure 2. Subtracting the first mode $c_1(t)$ and the second mode $c_2(t)$ from the original data, the smoothing result is shown as a solid line in figure 2. Rapid fluctuations in the original data are eliminated.

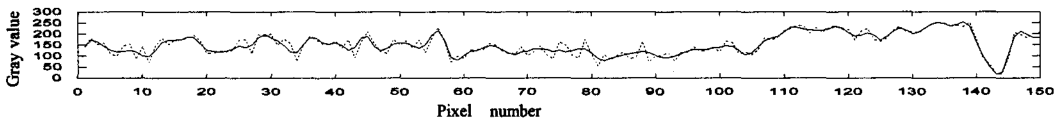

Figure 2. Illustration of one-dimensional data smoothing result. The solid line is the smoothed data, and the dotted line is the original data X(t).

2.3. Image Data Smoothing

The aforementioned data smoothing method can easily be applied to image data. We employ the One-Dimensional Data Smoothing Method to an image in four directions: horizontal (0^o), vertical (90^0), right diagonal (45^0), and left diagonal (-45^0) respectively, to obtain four directional smoothed images as shown in figure 3

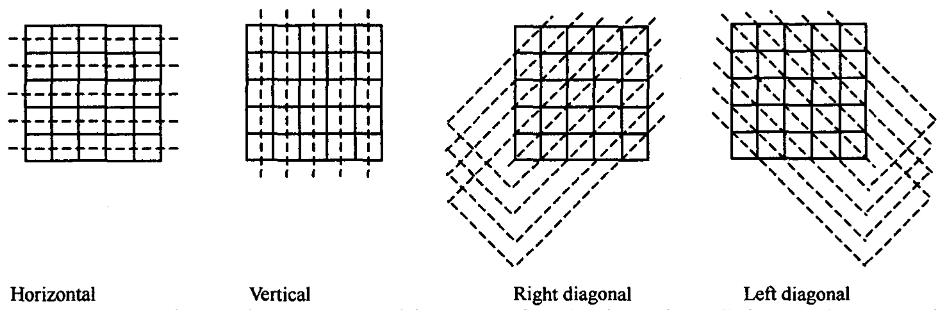

Figure 3. An n by n image is decomposed into 1-D signals along four different directions: horizontal, vertical, right diagonal (-45^0), and left diagonal (45^0), respectively. Each signal consists of n pixels (Dong *et al.* 2001).

2.4. Image reconstruction

For a given pixel p(i,j), there are five values, the original $p_o(i,j)$, the pixel smoothed along the horizontal $p_h(i,j)$, the pixel smoothed along the vertical $p_v(i,j)$ and two pixels smoothed along the left diagonal (-45) $p_{dl}(i,j)$ and the right diagonal (45

) $p_{dr}(i,j)$. The image is reconstructed in such way: if the local edge direction is horizontal, the $p_h(i,j)$ is used to reconstruct the image $p_r(i,j)$, and so on; if the edges can not be detected, the mean of pixels in 7×7windows is used to reconstruct the image $p_r(i,j)$.

$$P_r(i,j)=\begin{cases} P_h(i,j)\cdots\cdots\cdots & \text{Horizontal} \\ P_v(i,j)\cdots\cdots\cdots & \text{Vertical} \\ P_{rs}(i,j)\cdots\cdots\cdots & 45^\circ \\ P_{ls}(i,j)\cdots\cdots\cdots & -45^\circ \\ \left(\sum_{k=-3}^{k=3}\sum_{l=-3}^{l=3} p_o(i+k,j+l)\right)\Big/49 & \text{No edge} \end{cases} \quad \text{Edge direction}$$

Ⅲ. Evaluation of results

For comparative purposes the method proposed also was evaluated against 4 standard filters: Enhanced Lee (Lopes et al. 1990), Enhanced Frost (Lopes et al. 1990) Gamma (Lopes et al.1993) and Kuan (Kuan et al. 1987). A 255 by 255 pixel Chinese L-band SAR one-look image, acquired from a Beijing suburb and its five smoothed images are shown in figure 5 for evaluation. Since a moving window is required in the Enhanced Lee, Enhanced Frost, Gamma, and Kuan filters, moving windows with the size 3 by 3 are used. The 3 by 3 window is used for preserving edge information.

The conventional evaluation of a filter includes several criteria such as mean preservation, edge preservation, and reduction of the standard deviation. However, the authors consider that the quality of visual appearance is the most important because of the high sensitivity of human eyes to appearance of the images. Therefore, an optimal speckle suppression method should be best in terms of the quality of visual appearance, mean preservation, edge preservation, and reduction of the standard deviation.

Comparing the images in figure 5 shows that the image processed by the proposed method is in focus, while the images processed by other methods are blurred, in other word, the visual appearance of the image processed by the proposed method is best. Table 1 shows the results of statistical analysis for the original image, and its five smoothed images shown in figure 4. From table 1, we can see that the method proposed can effectively preserve the mean.

Original

Enhanced Lee

Enhanced Frost

Gamma

Kuan

Han *et al* proposed

Figure 4. Comparison of different filtering results. The original image is Chinese L-SAR one-look image (255 by 255pixels).

In terms of edge preservation, edge preservation index (EPI) is defined as

$$EPI = \frac{\sum \begin{pmatrix} |p_s(i,j) - p_s(i+1,j)| + \\ |p_s(i,j) - p_s(i,j+1)| \end{pmatrix}}{\sum \begin{pmatrix} |p_o(i,j) - p_o(i+1,j)| + \\ |p_o(i,j) - p_o(i,j+1)| \end{pmatrix}}$$

Where $p_s(i,j)$ is value of the smoothed image pixel, $p_o(i,j)$ is value of the original image pixel, the $p_s(i,j)$,and $p_o(i,j)$, are in edge area where intensity sharply varies. I is row number, and j is column number. The larger value of EPI is, the filter ability of edge preservation is more powerful. From table 1, we see that the proposed method is powerful in terms of edge preservation. The other methods show the poor performance. One 15 by 15 pixel homogeneous sub-areas labelled as Area Ⅰ taken from the original image and smoothed images in figure 5 are chosen for evaluating reduction of the standard deviation. From table 1, the method proposed can effectively reduce the standard deviation. From above comparison and analysis, we can see that the method proposed can effectively preserve the mean of image, preserve edges, reduce the standard deviation, and show good quality of visual appearance of the image after processing.

Table1. Comparison of speckle suppression ability.

Filter	Edge Preservation Index (EPI)	Area Ⅰ	
		STD	Mean
None (Original image)	1	1	1
Enhanced Lee	0.403598	0.376503	1.0257408
Enhanced Frost	0.394277	0.376503	1.0257408
Gamma	0.407191	0.376068	1.0211868
Kuan	0.410772	0.379958	0.9984634
Han *et al* proposed	0.799246	0.236033	0.9974296

Note: Area Ⅰ is a uniform area with size of 15 by 15 pixels, its original mean value is 107.378 and its original STD value is 27.1217.

4.Conclusions

An optimal SAR image speckle filter has been presented in this paper. Application to SAR images has shown that the effectiveness of the method is quite satisfactory in both speckle reduction and edge preservation, and at the same time, the smoothed image is also satisfactory in visual appearance.

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