Analysis of Speckle Noise Reduction in Synthetic Aperture Radar Images

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***Abstract*— Synthetic aperture radar (SAR) is an active imaging system that can achieve high resolutions both in range and azimuth. Speckle noise is one of the most critical disturbances that alter the quality of SAR coherent images. Before using SAR images in automatic target detection and recognition, the first step is to reduce the effect of speckle noise. In this paper, filtering techniques have been used on the input image and statistical parameters are calculated for the output images obtained from all filters for performance measurement and these are implemented in MATLAB.**

Keywords*— Synthetic aperture radar (SAR), speckle noise, statistical parameter.

I. INTRODUCTION

The idea behind SAR is to synthesize the effect of large aperture by moving small aperture radar along the flight path to obtain much finer resolution. While moving along the flight path, the SAR system records reflected waves from the imaged surface at different instants. Coherent processing of this reflected waves from the illuminated area of different range and azimuth results in the formation of 2-D SAR images [1]. However, such recorded SAR raw data contain unwanted artifacts, which result in granular appearances in SAR image. Those granular parts of SAR image are known as speckle, which is multiplicative in nature and degrades the SAR image quality significantly, leading to loss of crucial information. Therefore, speckle filtering is a critical preprocessing step for many SAR image processing tasks, such as segmentation and edge detection.

Several methods have been proposed for speckle noise reduction in SAR images. Some methods average out the speckle noise by taking multiple "looks" at a target in single radar sweep [3]. The average in this case is the incoherent average of the look [17]. The other methods involve signal processing using adaptive and non-adaptive filters. Non-adaptive filtering, such as Mean and Median filters, is simpler to implement and requires less computational power, while adaptive speckle filtering is better in preserving edges and details in high-texture areas such as forests and urban areas [8].

In this paper, the adaptive methods concern for eliminating speckle noise in SAR images. In Section II, gives a brief review of SAR despeckling methods that are present in literature. In section III, the Adaptive despeckling filters and algorithm for speckle noise reduction are discussed for SAR images. In Section IV, estimation of statistical parameter for performance measurement is explained. In section V, an experimental result for applying these filters on some real SAR images and compares it with existing speckle removal methods. Finally, in Section VI, we conclude the paper.

II. A SHORT OVERVIEW OF SAR DESPECKLING METHODS

Many adaptive filters for SAR image denoising have been proposed in the past. The simplest approaches to speckle reduction are based on temporal averaging, median filtering, and Wiener filtering. Ahmed S. Mashaly et al. [8] proposed Adaptive morphological filter method significantly suppressing speckle noise and preserving the potential targets.

Recently, there has been considerable interest in using the wavelet transform as a powerful tool for recovering SAR images from noisy data [4]. When multiplicative Contamination is concerned; multiscale methods involve a preprocessing step consisting of a logarithmic transform to separate the noise from the original image. Then, different wavelet shrinkage approaches are employed. More specifically, methods based on multiscale decompositions consist of three main steps: First, the raw data are decomposed by means of the wavelet transform, then the empirical wavelet coefficients are shrunk through a thresholding mechanism, and finally, the denoised signal is synthesized from the processed wavelet coefficients through the inverse wavelet transform. Alin Achim et al. [12] suggest method Wavelet-based image de-noising nonlinear SAR. Proposed method based on wavelet decomposition using daubechies and MAP processor is used to estimate signal and noise component instead of thresholding technique. Charles-Alban Deledalle et al. [3] proposed Patch based Non local estimation is used to eliminate speckle with increasing spatial resolution and gives better performance for speckle reduction in SAR intensity image. Method focusing on two methods which are measuring patches similarity and estimate parameters of interest from similar patches. Alin Achim et al. [11] suggest method MAP filter Based on the Heavy-Tailed Rayleigh Model. Initially shows the sub-band decomposition of log transformed SAR images can be accurately modeled by alpha-stable distributions. Xie *et al.* developed a similar method by fusing the wavelet Bayesian denoising technique with Markov-random-field-based SAR image regularization.

III. ADAPTIVE DESPECKLING FILTERS FOR SAR IMAGES

The de-speckling filtering is to move a kernel over each pixel in the image and apply a mathematical calculation using the pixel values under this kernel, and then replace the central pixel with the calculated value. The kernel is moved along the image one pixel at a time until the entire image has been covered. In the preceding subsections, we will give a brief review on the mathematical principles of these filters as we will use them in the comparative study with filter.

A. Lee and enhanced-Lee filters

The lee filter is basically used for speckle noise reduction. This filter is based on the assumption that the mean and variance of the pixel of the interest is equal to the local mean and variance of all pixels with in the moving kernel [20]. The resulting gray level value R for the smoothed pixel is:

$$R = I_c * W + I_m * (1 - W) \qquad (3.1)$$

Where, $W = (1 - C_u^2 / C_i^2)$

$C_u = \sqrt{(1/ENL)}$

$C_i = S / I_m$

S= standard deviation of intensity within filter window

I_c=central pixel of filter window

I_m=mean intensity with filter window

The weighting function W is a measure of the estimated noise variation coefficient C_u with respect to the image variation coefficient C_i. The number of looks parameter ENL is the effective number of looks of the radar image. ENL is used to estimate the noise variance and it controls the amount of smoothing applied to the image by the filter. Moreover, ENL should be close to the actual number of looks, but it may be changed if the image has undergone resembling. The user may experimentally adjust the ENL value to control the effect of the filter. A small ENL value leads to more smoothing while a large ENL preserves more image features.

Enhanced-Lee filter divided the SAR image into areas of three classes [16]. The first class corresponds to the homogeneous areas in which the speckles may be eliminated simply by applying a low pass filter, or equivalently, averaging in multi-look processing. The second class corresponds to the heterogeneous areas in which the speckles are to be reduced while preserving texture. The third class is the areas that include the isolated point targets that the filter should preserve. The resulting grey level value R for the smoothed pixel is:

$$R = \begin{cases} I_m & for\ C_i \le C_u \\ I_c * W + I_m * (1 - W) & for\ C_u < C_i < C_{max} \\ I_c & for\ C_i \ge C_{max} \end{cases} \qquad (3.2)$$

Where,W=$e^{(-dampfactor * (C_i - C_u)/(C_{max} - C_i))}$

$C_{max} = \sqrt{(1+2/ENL)}$

B. Frost and and enhanced-Frost filters

Frost filter is designed to smooth out noise while retaining edges or shape features in the image through using an exponentially damped convolution kernel [19]. This kernel adapts itself according to the statistics of the local features. The implementation of this filter is based on defining a circularly symmetric filter with a set of weighting values M for each pixel:

$$M = e^{-AT} \qquad (3.3)$$

Where, T is the Euclidean distance between the central pixel of the filter window and its neighbor's pixels, while Damp Factor is an exponential damping factor and A is given by:

$$A = Dampfactor * C_i^2$$

The smoothed pixel value given by:

$$R = \frac{(P_1 * M_1 + P_2 * M_2 + ... + P_n * M_n)}{(M_1 + M_2 + ... + M_n)} \qquad (3.4)$$

Where, $P_1 ... P_n$ are grey levels of each pixel in filter window, and $M_1 ... M_n$ are weights computed for each pixel as defined above. The use of large values for damp factor allows better preservation of sharp edges, but reduces the smoothing effect. The use of small values for damp factor increases the smoothing effect, but does not preserve sharp edges well.

The enhanced Frost filter is similar to the enhanced Lee filter [16] in that it considers three different types of image areas separately: homogeneous, heterogeneous, and areas of isolated point targets. The filter output is:

$$R = \begin{cases} I_m & for\ C_i \le C_u \\ R_f & for\ C_u < C_i < C_{max} \\ I_c & for\ C_i \ge C_{max} \end{cases} \qquad (3.5)$$

Where, R_f is the result of convolving the image with a circularly symmetric filter whose weighting values M for each pixel is:

$$M = e^{-AT}$$

Where,A=$dampfactor * (C_i - C_u)/(C_{max} - C_i)$

$$Rf = \frac{(P_1 * M_1 + P_2 * M_2 + ... + P_n * M_n)}{(M_1 + M_2 + ... + M_n)}$$

C. Kuan and enhanced-Kuan filters

The kuan filter transforms the multiplicative noise model into an additive noise model [18]. This filter is similar to Lee filter but uses a different weighting function. The resulting grey level value R for the smoothed pixel is:

$$R = I_c * W + I_m * (1 - w) \qquad (3.6)$$

Where, $W = (1 - \frac{C_u^2}{C_i^2}) / (1 + C_u^2)$

The enhanced kuan filter is similar to the enhanced Lee filter in that it considers three different types of image areas separately: homogeneous, heterogeneous, and areas of isolated point targets. The filter output is:

$$R = \begin{cases} I_m & for\ C_i \le C_u \\ R_f & for\ C_u < C_i < C_{max} \\ I_c & for\ C_i \ge C_{max} \end{cases} \qquad (3.7)$$

Where, $R_f = I_c * W + I_m * (1 - w)$

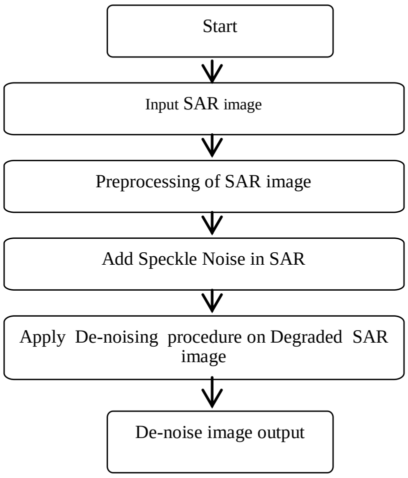


Figure 1: Algorithm for Speckle Noise Reduction in SAR Images

D. *Gamma MAP filter*

To apply the MAP (Maximum a posteriori) approach to speckle reduction, the a priori knowledge of the probability density function of the scene is required. With the assumption of a gamma distributed scene, the GMAP filter is derived with the form similar to enhanced Lee [16] with different filter model (R_f) for heterogeneous areas:

$$R_f = (B * I_m + \sqrt{D})/(2 * A) \tag{3.8}$$

Where, $C_{max} = \sqrt{2} * C_u$

$A = (1 + C_u^2)/(C_i^2 - C_u^2)$

$B = A - ENL - 1$

$D = (I_m^2 * B^2) * (4 * A * ENL * I_m * I_c)$

IV. ESTIMATION OF STATISTICAL PARAMETERS

The parameters which are used in the filter performance evaluation are Signal to Noise Ratio (SNR), Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR) and Correlation Coefficient (CoC).

A. *Signal to noise ratio (SNR)*

SNR compares the level of desired signal to the level of background noise. The higher the SNR ratio, the lesser obtrusive the background noise is. SNR in decibels is defined as [4]:

$$SNR = 10\log(\sigma_g^2 / \sigma_e^2) \tag{4.1}$$

Where,$\sigma_g^2$is the variance of the noise free image and σ_e^2 is the variance of error (between the original and denoised image). Brighter regions have a stronger signal due to more light, resulting in higher overall SNR.

B. *Root mean square error (RMSE)*

Mean square error (MSE) is given by:

$$MSE = \sum_{i=j=1}^{N} [f(i,j) - F(i,j)]^2 / N^2 \tag{4.2}$$

Where, f is the original image F is the image denoised with some filter and N is the size of the image.

$$RMSE = \sqrt{MSE} \tag{4.3}$$

RMSE [4] is an estimator in many ways to quantify the amount by which a filtered/noisy image differs from noiseless image.

C. *Peak signal to noise ratio (PSNR)*

PSNR is the ratio between possible power of a signal and the power of corrupting noise that affects the fidelity of its preservation [4].

$$PSNR = 20\log_{10}(255/\text{RMSE}) \tag{4.4}$$

Higher the PSNR gives lower the noise in the image, i.e. higher image quality.

D. *Correlation Coefficient (CoC)*

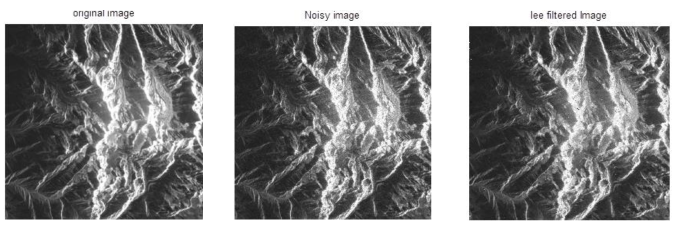
Correlation gives the linear relationship between two signals [4] with respect to strength and direction, and its value lies between -1 to +1. The correlation is 1 for increasing linear relationship, -1 for decreasing linear relationship, for all the other cases the value lies between -1 to +1.

$$CoC = \frac{\sum (g - \dot{g})(\hat{g} - \dot{g})}{\sqrt{\sum (g - \dot{g})^2 (\hat{g} - \dot{g})^2}} \tag{4.5}$$

Where, g and ĝ are original and images de-noised with some filter respectively, and ġ and ĝ are the mean's of the original image and image de-noised with a few filters respectively.

V. EXPERIMENTAL RESULTS

In this section, simulation results are obtained by processing several test SAR images using filtering techniques and we compare the results with speckle filtering methods. In order to be able to quantify the improvement achieved by our method, we have first degraded original "noiseless" images with synthetic speckle in a controlled manner.



(a) (b) (c)

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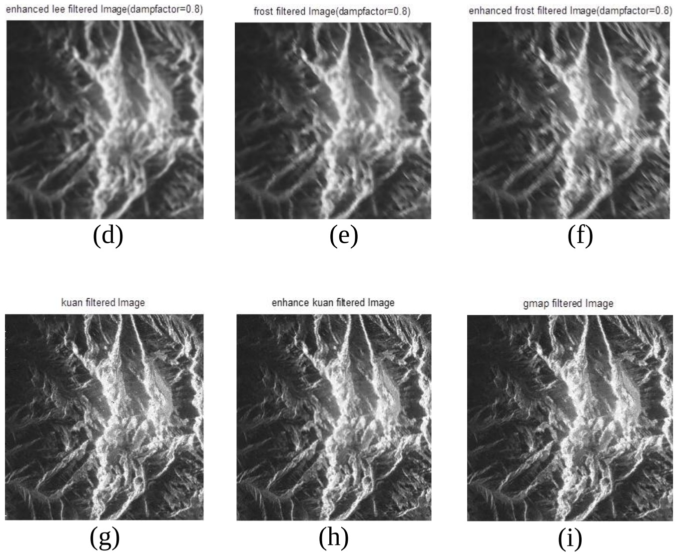

Figure 2: Results taken at variance= 0.01 and ENL=3025 on SAR image 'gangotri.jpg'. (a) Original image [22] (b) Noisy image (c) Lee filter (d) Enhanced lee filter (damp factor=0.8) (e) Frost filter (damp factor=0.8) (f) Enhanced Frost filter (damp factor=0.8) (g) Kuan filter (h) Enhanced kuan filter (i) Gamma MAP filter

Table I: Comparison of different de-noising Filters for SAR image 'gangotri.jpg' Corrupted by Speckle Noise with variance = 0.01

Filter	SNR (dB)	PSNR (dB)	MSE (dB)	RMSE (dB)	CoC	Elapsed time (sec.)
Lee filter	12.4167	19.4113	744.6480	27.2882	0.9045	14.073607
Enhanced Lee	15.4810	22.4756	367.7198	19.1760	0.9492	14.102054
Frost filter	15.3425	22.3371	379.6414	19.4844	0.9474	36.745613
Enhanced frost	15.1290	22.1236	398.7726	19.9693	0.9435	36.953505
Kuan filter	12.4193	19.4139	744.1933	27.2799	0.9045	13.988123
Enhance kuan filter	20.9499	27.9445	104.3828	10.2168	0.9853	13.321367
Gmap filter	20.9476	27.9422	104.4375	10.2195	0.9853	13.397407

Table II: Comparison of different de-noising Filters for SAR image 'gangotri.jpg' Corrupted by Speckle Noise with Variance = 0.4

Filter	SNR (dB)	PSNR (dB)	MSE (dB)	RMSE (dB)	CoC	Elapsed time (sec.)
Lee filter	5.4843	12.4789	3674.4	60.6171	0.6165	16.317789
Enhanced Lee	11.8286	18.8232	852.6226	29.1997	0.8877	13.548386
Frost filter	10.2552	17.2498	1224.9	34.9987	0.8175	35.249355
Enhanced frost	9.7874	16.7820	1364.2	36.9351	0.7946	36.327350
Kuan filter	5.4868	12.4814	3672.4	60.6000	0.6166	15.350475
Enhanced kuan	5.4879	12.4825	3671.4	60.5921	0.6166	15.321556
Gmap filter	5.4490	12.4436	3704.4	60.8637	0.6130	13.895759

VI. CONCLUSION

The use of filter in Digital Image Processing improves the image to a great extent. The model preserves the appearances of structured regions. In case of Synthetic Aperture Radar (SAR) Images, Texture and land surfaces have been enhanced. The performance of the algorithm has been tested using statistical parameter measures. Many of the methods are failures to remove speckle noise present in the Synthetic Aperture Radar (SAR) images, since the information about the variance of the noise may not be able to identify by the methods. The Performance of the Speckle noise reduction model for Synthetic Aperture Radar is well as compared to other filters. Lee filters smoothest the image data, without removing edges or sharp features in the images. Enhanced lee filter and enhanced frost filter divide the image into areas of three classes which are homogeneous area, heterogeneous area and isolated point. In the homogeneous area in which speckle eliminated by averaging the multilook processing, in the heterogeneous area in which speckle are reduced while preserving the texture and preserving texture in isolated point target. Kuan, Enhanced kuan and Gamma MAP filter reduces speckle while preserving edges in SAR images.

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