An Approach to compare the performance of Different Transform Domain Filtering with Firefly Algorithm in Despeckling of SAR images

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Abstract

This paper provides a comparative study of the performance of different Transform Domain filters like Wavelet, Contourlet, Bandelet and Curvelet with Firefly Algorithm (FA) applied to despeckle Synthetic Aperture Radar (SAR) image. Initially the feature enhancement and edge detection of speckled SAR image are integrated with improved gain function by shrinking and stretching the Wavelet Co-efficients. Then to optimize the best oriented quality parameters of the despeckled image, FA is applied.The procedure is continued for Contourlet, Bandelet and Curvelet Transforms with FA. The experimental results are compared and concluded with best result.

Keywords : Transform Domain Filters, SAR image, Despeckling, Firefly Algorithm, ENL, PSNR.

Introduction

SAR images have many applications like Ice monitoring, Crop Production, Disaster monitoring like Forest fires, Floods, Volcanic eruptions and Oil spilling. But due to inherent nature of scattering effect, SAR images are affected by speckle noise. Speckle noise suppress the delectability of the details of the image, as it reduces the intensity level of the image and tends to blur the image details [1]. As the power of the signal increases the speckle noise also increases by same amount. Therefore speckle noise is a multiplicative noise and it should be removed.

The speckle noise model can be represented in an equation (1) as,

$$f_{(i,j)} = g_{(i,j)} * n_{(i,j)} + h_{(i,j)} \qquad (1)$$

where $f_{(i,j)}$ is the measured pixel level,

$g_{(i,j)}$ is the desired pixel reflectivity,

$n_{(i,j)}$ is the multiplicative noise and

$h_{(i,j)}$ is the additive noise.

Here i, j represent the indices of the spatial location.

Logarithmic compression is applied to the SAR image to covert the multiplicative noise into additive white Gaussian noise which can be easily removed and is given as,

$\log [f_{(i,j)}] = \log [g_{(i,j)}] + \log [n_{(i,j)}]$ and rewritten as,

$$D(i, j) = X(i, j) + Y(i, j) \quad (2)$$

where $\log [f_{(i,j)}]$ is denoted as D (i, j) and the terms $\log [g_{(i,j)}]$ and $\log [n_{(i,j)}]$ are denoted as X (i, j) and Y (i, j) respectively.

Researchers developed many techniques to retain the image details by filtering the speckle noise. Multiple Look Processing on the SAR image in frequency domain [2] and averaging statistically dependent looks on the same scene is one of the techniques employed. This technique enhances the image resolution at the expense of blurring. Later on the speckle reduction by the spatial filtering have been developed using Median, Lee, Frost and Kaun filters. These type of filters have low computation complexity but blur the edges of the image with single scale representation either time or frequency [3]. Also in single scale representation, it is difficult to differentiate signal from noise. However it is an unsolved problem and no comprehensive method to solve all the constraints taken into consideration. Transform domain filters overcome all the limitations with high efficiency. Over last decade, researchers developed many multi-scale Wavelet, Contourlet, Bandelet, Curvelet and combination of two transforms methods for noise reduction and feature enhancement [4] – [9].

The rest of the paper is organized as follows. Section II describes the different Transforms applied for smoothening SAR image. Despeckling and feature enhancement of the image by improved gain function and Firefly Algorithm employed to optimize the parameters of the despeckled SAR image are discussed in section III. Section IV explains the Adaptive Despeckling and Enhancement of SAR image. The experimental results and analysis of comparison is dealt in section V. Section VI ends with conclusion.

II TRANSFORMS

Transform domain speckle removal process with edge preservation overcome the limitations existed in the previous techniques with Spatial filtering.

A.Wavelet transform

Wavelet transform is the inheritance and development of traditional Fourier transform. Wavelet transform is a basic and powerful tool acts on the despeckling of SAR images because of its properties of time and frequency localization, multiresolution, sparsity and decorrelation. Wavelet transform method is practically very flexible and very much suitable in image denoising and enhancement. The application of Wavelet transform is essential in image processing and classified into three classes as Continuous, Discrete and Multiresolution based discrete wavelet transform[10]-[11].

B.Contourlet Transform

The preservation of the edges should be definitely made while despeckling of SAR images. In order to effectively capture image edges and contours, Do and Vetterli proposed a multi-scale and multidirectional image representation method using Contourlet Transform [12] – [15]. The Contourlet transform exploits smoothness of contour effectively by considering a number of directions following the contours. It is observed that the basic wavelet transform is adapted to point singularities with a problem of orientation selectivity. This major drawback is overcome by the Contourlet transform which represents the multi-scale geometric analysis.

C. Bandelet Transform

In image processing or image representation the geometry regularity is the challenging one. Edges with sharp image transition are very difficult to be represented in an image. To achieve better representation some geometric regularity of the functions are applied but not possibly obtained using Wavelet or Fourier basis. On further development, Bandelet basis was introduced for the optimal geometric representation of digital images in discrete domain. To estimate the geometric regularity, digital image information is achieved by "Multiresolution analysis", thereby decomposing the digital image using Bandelets and making directional analysis on orthogonal Wavelet coefficients. By the use of wavelet bank with directional orthogonal filters, the orthogonal wavelet coefficients are computed. In directional analysis, the orthogonal directional projection and one dimensional wavelet transform along the direction of the geometry are realized [16]. Each geometric direction leads to a different transform so that an optimal set of filter could be found by the application of optimization technique. In Bandelet transform, 2D wavelet transform on the data and then 1D wavelet transform along geometry are implemented [17]. The signal possesses both orthogonality and symmetry which store energy to an amount as much as possible in the application of image processing.

D. Curvelet Transform

The Curvelet transform was introduced by Candes and Donoho in 2000 and involves the analysis of Ridgelet Transform in step by step procedure. This process is slow and researchers develop a new version with discarding of Ridgelet transform with discarding of preprocessing step of Ridgelet transform so that the redundancy of the transform is reduced with improvement in speed. The importance of Curvelet transform is that it needs only less co-efficients for representation producing a smoother edge than Wavelet edge.[18].Curvelet transform is considered to be the latest development among non adaptive transforms. Curvelet transform provides more space representation of the image with inspired directional elements and better ability to represent edges and other singularities along curve than Wavelet transform[19]. Also Curvelet have good geometric feature and variable anisotropy.

III DESPECKLING AND FEATURE ENHANCEMENT OF SAR IMAGE

A. Improved Gain Function

➢ The improved gain function is deliberately achieved by shrinking and stretching the co-efficients of the Wavelet transform. Then thresholding is applied to despeckle the image so that each pixel in an image is replaced if the pixel image intensity level is less than some fixed constant called threshold. Here if a Wavelet sub band coefficients are smaller than a predefined threshold it will be set to zero; otherwise the absolute value shrinks by the value of threshold. This function is known as Soft thresholding. Same as soft thresholding, if a Wavelet sub band coefficients is smaller than a predefined threshold it will be set to zero; otherwise it is kept unchanged, this function is known as Hard thresholding. So it is seen that the thresholding step performs the initial act of image denoising by removing the unaccepted values less than threshold value. Here hard thresholding is applied.

- Starck et. al [20] introduced image despeckling using hard thresholding of Curvelet co-efficients represented in Eq. (5) and then Starck et. al [21] proposed the modified method to enhance the edges in an image with improved gain function. Here the gain function k_a is improved by modifying the bandelet coefficients in order to enhance edges in SAR image. The gain function k_a is represented as,

$$k_{a(i,j)} = \begin{cases} 1 & ,if\ i < aj \\ \frac{i-aj}{aj}\left(\frac{n}{2aj}\right)^x + \frac{2aj-i}{aj} & ,if\ aj \le i < 2aj \\ \left(\frac{n}{i}\right)^x & ,if\ 2aj \le i < n \\ \left(\frac{n}{i}\right)^y & ,\ if\ i \ge n \end{cases} \quad (3)$$

where j = the noise standard deviation

x = the degree of non- linearity

y = the dynamic range compression

a = the normalization parameter

n=a parameter and its value under which coefficient are amplified.

The Eq. (5) works under two conditions that when,

i) n = kj where k is an additional parameter.

ii) n = þMc with þ < 1. Mc – Maximum bandelet coefficient thus holds of relative band.

This foundation includes three T_1, T_2, and T_3 which meet T_1 = aj, T_2 = 2T, T_3 = n and $T_1 < T_2 < T_3$.

If n = kj the gain function is improved effectively but by taking k as an additional parameter neither reduce the noise nor amplify the noise. Hence hard thresholding is applied in the gain function to enhance the features of SAR image by simultaneously suppressing the speckle by modifying the gain function as in Eq. (5) to Eq. (6) as,

$$k_{a(i,T)} = \begin{cases} 0 & ,if\ i < T_1 \\ \frac{i-T_1}{T_1}\left(\frac{T_3}{T_2}\right)^x + \frac{T_2-i}{T_1} & ,if\ T_1 \le i < T_2 \\ \left(\frac{T_3}{i}\right)^x & ,if\ T_2 \le i < T_3 \\ \left(\frac{T_3}{i}\right)^y & ,if\ i \ge T_3 \end{cases} \quad (4)$$

The main disadvantage in the improvement of gain function is to properly selecting the parameters T_1,T_2,$T_{3,}$ x & y.

B. Optimization Technique in Image Enhancement

Firefly Algorithm (FA) was developed by Xin-She Yang [22] at Cambridge University in 2007. FA is an optimization algorithm inspired by the behavior and motion of fireflies [23].

Numerous firefly species occupied in the sky produce short and rhythmic flashes in the moderate temperature region. Mostly specific species produce specific pattern. A kind of pattern formed by attraction of male and female species depends upon many factors like the rhythm of the flashes, flash rate and the flash time. Fireflies communicate with each other only at a limited distance normally few hundred meters at night. The light is observed by air and becomes weaker, also the intensity of light decreases as the distance from the light source increases.

Firefly Algorithm follows rules as,

- All the fireflies are unisex that means that one firefly is attracted to other firefly irrespective of their sex.
- Attractiveness and brightness are proportional to each other and so for any two flashing fireflies, the firefly with less brightness tend to move to reach the one which is brighter also decrease with their distance decreases. If the brightness of all fireflies is same they will move randomly.
- The objective functions determine brightness of a firefly.

The brightness is proportional to the value of the objective function for a maximization problem. The variation in light intensity and formulation of attractiveness are the main important points in Firefly algorithm since the attractiveness of a firefly is determined by its objective function.

Some initialization has to be made in the FA algorithm including,

1) γ: the light coefficient of absorption
2) d: the particular distance from the light source
3) s: the domain space.

The attraction of firefly i , to another brighter firefly j, is expressed as,

$$p_i = p_i + A_o e^{-\gamma d_{ij}^2}(p_j - p_i) + \alpha \epsilon_i \qquad (5)$$

where, $A_o\, e^{-\gamma d_{ij}^2}(p_j - p_i)$ is due to attraction, α is a randomization parameter and ϵ_i is a vector of a random number uniformly distributed in [0,1]..A_0 is considered as 1 and $\alpha \epsilon_i$ [0, 1]. The parameter γ is a very important factor which determines the behavior of the fireflies. The contrast of attractiveness is characterized by γ and also it determines the speed of convergence. Theoretically $\gamma \epsilon [0, \alpha]$ but practically its value is reduced to [0, 1] which is determined by the characteristic length 'Γ' of the system to be optimized. In most of the variation of γ is taken between 0.1 and 10.

Firefly Algorithm for image Enhancement

In conjunction with the above algorithm mostly and derivations, the strategy is given below to meet the problem objective,

1) Initial population: total number of image pixels.
2) Max. Gen: intensity variation through iteration.
3) If the previous pixel value is greater than current pixel value after considering the fitness evaluation, which is replaced, depending upon the global intensity values of the image.
4) As attractiveness varies with distance, the boundary value of the window size is considered, any value that crosses the boundary is ignored.

5) After each iteration, the global best in consideration in accordance to the window size is updated and the highest intensity value of that iteration is considered for the previous update. The rank of the firefly is updated.

6) The value of the absorption rate is considered to give a smoothing effect for the image and the attractiveness which is then updated according to the rank matrix.

FA is potentially powerful than a favorable optimization tool [26]. Also FA includes the self-improving process and is better than PSO in terms of convergence time.

Firefly algorithm does not have the record of previous history of better situation for each firefly and this causes them to move regardless of its previous better situation, and they may ended by missing their situations.

IV Adaptive Despeckling and Enhancement of SAR image

The despeckling and enhancement algorithms used for SAR images can be explained as step by step procedure and it is shown in Fig. 1..

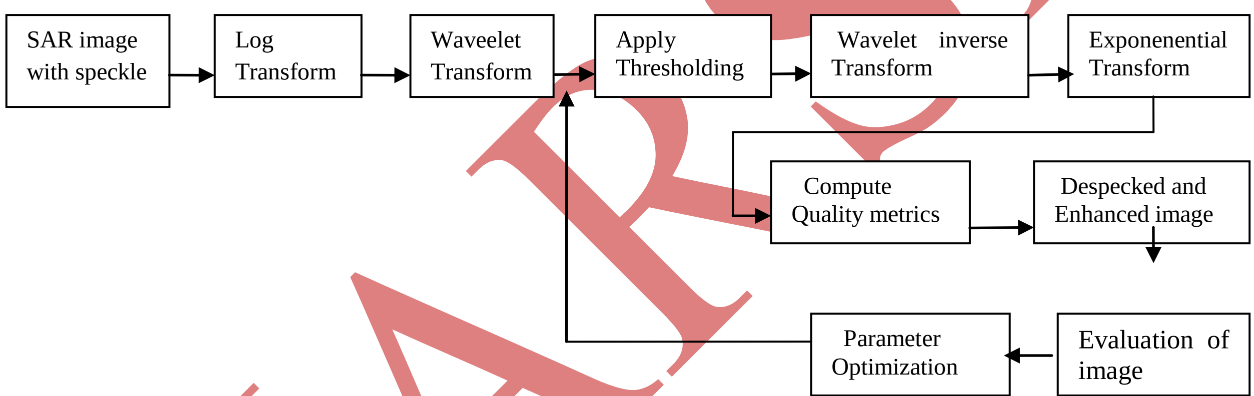


Fig. 1 Block diagram of the proposed despeckling and enhancement of SAR image.

The step by step procedure of the block diagram is explained as follows:-

- The original noisy SAR image is applied to the Logarithmic transformation block in which the multiplicative noise is converted into additive Gaussian noise as discussed in equation (2). There the original SAR image, $I_{(m,n)}$ is changed to $I'_{(m,n)}$ with removable additive noise where 'm' and 'n ' represents the row and column of the image.
- Applying Wavelet transform to $I'_{(m,n)}$ up to 'n' and 'm' directional decomposition at each level, the Wavelet co-efficients are achieved.
- Then thresholding of Wavelet transformed image is performed. Thresholding is applied to the image to despeckle the image so that each pixel in an image is replaced if the pixel image intensity level is less than some fixed constant called threshold. Here if a Wavelet sub band coefficients are smaller than a predefined threshold it will be set to zero; otherwise the absolute value shrinks by the value of threshold. This function is known as soft thresholding. Same as soft thresholding, if a Wavelet sub band coefficients is smaller than a predefined threshold it will be set to zero; otherwise it is kept unchanged, this function is known as hard thresholding. So it is seen that the

thresholding step performs the initial act of image denoising by removing the unaccepted values less than threshold value. Here hard thresholding is applied.

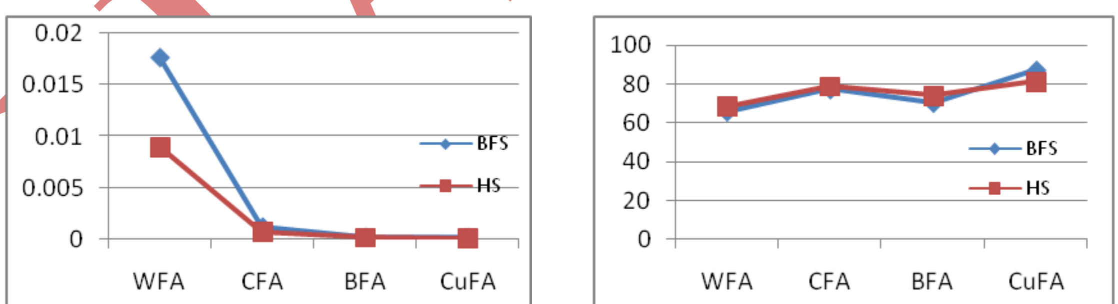
The main disadvantage in the improvement of gain function is to properly selecting the parameters T_1,T_2,T_3, x & y. Hence the parameters are optimized using the global search Firefly Algorithm.

- The inverse Wavelet transform on the threshold image and exponential transformation is carried over to obtain the despeckled image.
- The Quality metrics for the despeckled image are computed.
- Each despeckled and enhanced image is evaluated using evaluation function of FA.

Repeat the steps till stop condition of the FA is satisfied. The procedure is repeated with Contourlet, Bandelet and Curvelet Transforms and the results are compared.

V. Result Analysis and Discussion

Image quality is a characteristic of an image that measures the perceived image degradation. In this section, analysis of simulated results of despeckled SAR image is presented. The comparison with the experimental results about despeckling of SAR images with Wavelet,Contourlet, Bandelet and Curvelet domain, all optimized using FA are done. Two noisy images say, the Terrain of Bedfordshire, South East England and Horsetrack near Alburquerque are taken for experimental purpose of despeckling. MATLAB Tool is utilized for implementation and the simulated results are obtained. The performance of the despeckled image is quantitatively determined by measuring all the Quality metrics like Mean Square Error(MSE), Equal Number of Looks(ENL), Speckle Suppression Index (SSI), Speckle Suppression and Preservation Index(SMPI), Edge Save Index Vertical(ESI-V), Edge Save Index Horizontal(ESI-H) and Peak Signal to Noise Ratio(PSNR) of the image. From the graphical representation of parametric results shown in Fig.2, it is evident that Curvelet transform with Firefly has more Despeckling property when compared to Wavelet, Contourlet and Bandelet transforms with FA.



(a) (b)

Fig.2 Graphical representation of Quality parameters. a) MSE for Bedfordshire and Horsetrack images. b) PSNR for Bedfordshire and Horsetrack images.

The performance of the various despeckling method is compared inTable.1and presented a comparative study of various Transform domain filters in Despeckling of SAR image.

Table. 1 Comparison of Quality parameters of different Transform domain filters for SAR image

Image		Wavelet with FA	Contourlet with FA	Bandelet with FA	Curvelet with FA
Bedford shire	MSE	**0.0177**	**0.0012**	**0.00020**	**0.000193**
	ENL	6.9365	4.4170	19.7720	4.8084
	SSI	0.7951	0.9964	0.8391	1.0061
	SMPI	0.7945	0.9945	0.85756	1.0003
	ESI-V	0.8227	0.6856	1.0543	1.1021
	ESI-H	0.5398	0.7844	0.9360	1.2349
	PSNR	**65.661**	**77.2420**	**70.23**	**85.2742**
Horse Track	MSE	**0.0090**	**0.0008**	**0.00021**	**0.000147**
	ENL	5.8381	3.9763	20.2366	3.8283
	SSI	0.8228	0.9970	0.7126	1.0711
	SMPI	0.8218	0.9964	0.7410	0.9478
	ESI-V	0.9052	0.8246	0.6192	0.7982
	ESI-H	0.0344	1.0946	0.6062	0.8857
	PSNR	**68.606**	**78.9093**	**74.021**	**81.3192**

The Despeckling and enhacement algorithm based on Curvelet Transform with Firefly Algorithm compared with other three transform domain such as Wavelet, Contourlet and Bandelet transforms. From Table.1 it is found that the Curvelet Transform with FA produces better result by referring the Quality parameters MSE and PSNR which determines the noise reduction in despeckled SAR image. Here MSE is much reduced to .000193 for Bedfordshire and 0.000147 for Horsetrack SAR images. Likewise PSNR is much improved to 85.2742 using Bedfordshire and 81.3192 with Horsetrack SAR images among all transform domain filters.

VI Conclusion

In this paper, an adaptive method of speckle reduction and feature enhancement for SAR images based on Wavelet transform with Firefly algorithm have been proposed. An improved Quality metrics of the image is developed to integrate the speckle reduction with feature enhancement, by nonlinearly shrinking and stretching the co-efficients of Wavelet transform and optimized the parameters using Firefly Algorithm. The Firefly algorithm is applied to make the speedy convergence and avoid premature convergence in optimizing the parameters. The result is compared with Despeckling of SAR images using Contorlet, Bandelet and Curvelet transforms with Firefly Algorithm. After the analysis, it is concluded that the simulated and real SAR images were despeckled and their feature were enhanced which provide excellent performance of despeckling with Curvelet transform with Firefly Aour provides superior result compared to Wavelet, Contourlet and Bandelet transforms. This is computationally expensive due to iterative operation of Firefly Algorithm and improved version may be adopted by parallel operation which will reduce the computation time effectively and can be taken as future work.

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