Removal of Speckle Noise in SAR image using Curvelet Transform with Optimization

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ABSTRACT:

In this paper, it is explained about the removal of speckle noise present in Synthetic Aperture Radar (SAR) images using the Curvelet Transform and the results are optimized with Firefly Algorithm(FA). In image processing, the images obtained by Coherent imaging system consists of speckle noise which ts very difficult to remove. So it is a challenge for researchers to do the despeckle process so that to obtain the feature extraction and fine details of the SAR images.. Here it begins with shrinking and stretching the Curvelet co-efficients and by applying an improved gain function, the speckle reduction with feature enhancement is integrated. Then the quality of the despeckled image is determined by evaluating their quality parameters. To get the best oriented quality parameters of the despeckled image, an Evolutionary Computation technique FA is applied. The same procedure is repeated with the combination of Curvelet transform and another optimization technique called Modified Particle Swarm Optimization (MPSO). The final performance of despeckled image is compared and the experimental results show that the proposed method outperforms the Despeckling of image so that the texture and edge details of an image are preserved than the referenced state-of-the-art methods in terms of both noise reduction and image detail preservation. This implementation offers the exact reconstruction of the image with good stability, less Mean Square Error (MSE) and improved Peak Signal to Noise Ratio (PSNR).

Keywords: SAR image, Despeckling, Curvelet Transform, Firefly Algorithm, MSE and PSNR.

1 INTRODUCTION

Synthetic Aperture Radar plays a vital role in integrating information of the scene in all time and weather conditions with high spatial resolution. SAR images are used to interpret information and have many applications like Flood Control, Bio-mass estimation, Sea ice monitoring, Crop estimation, Oil spill monitoring and Soil moisture content measurement. But in acquiring SAR images many techniques are adopted, coherently subject to the presence of speckle that greatly degrades the fine details of the image (Goodman et al 1976, Tinku Acharya et al 2005) [1] [2]. Also the speckle reduces the efficiency of the post processing steps in image processing and makes it more difficult to interpret. So the first and crucial step in image processing is to remove

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the speckle noise so that the visual appearance of an image is improved significantly. There should be some means to suppress the multiplicative speckle noise and preserve all the scene features such as textures and edges. This can be achieved by different despeckling techniques.

As the power of the signal is proportional to the speckle noise, it increases with increase in speckle noise by the same amount. Therefore speckle is a multiplicative noise and it can be explained with a standard deviation equal to its pixel reflectivity value. The speckle noise model can be represented in an Eq. 1 as,

$$s_{(I,j)} = m_{(I,j)} \times n_{(I,j)} \quad (1)$$

where $s_{(i,j)}$ is the measured pixel level,
$m_{(i,j)}$ is the desired pixel reflectivity,
$n_{(i,j)}$ is the multiplicative noise and
here i, j represent the indices of the spatial location.
SAR signal is applied with logarithmic compression, which transforms the multiplicative noise into additive white Gaussian noise. This is given by Eq. 2 as,

$$\log [s_{(i,j)}] = \log [m_{(i,j)}] + \log [n_{(i,j)}] \quad (2)$$

and rewritten as,

$$D(i,j) = P(i,j) + Q(i,j) \quad (3)$$

where log sf$_{(i,j)}$] is denoted as D (i, j) and the terms log [$m_{(i,j)}$] and log [$n_{(i,j)}$] are denoted as P (i, j) and Q (i, j) respectively. Also the logarithmic conversion is used, so that the additive noise can be easily removed.

About two decades, researchers developed two methods to apply despeckling before and after image formation. One method is that employs multiple look processing or Equal Number of Looks (ENL) in frequency domain (Poornachandra et al 2005) [3] thereby averaging statistically dependent looks on the same scene. The ENL is defined as the square of the ratio of Mean and Standard Deviation and in given by,

$$ENL = \left(\frac{mean}{SD}\right)^2 \quad (4)$$

The efficiency of smoothing noise over homogeneous areas is determined by this parameter ENL. If ENL is high, the efficiency of smoothing will also be high.
This technique enhances the radiometric resolution at the expense of blurring. Later on the classical spatial filters in spatial domain like Median filter, Lee filter (Lee 1981) [4], Kuan filter (Kuan et al 1987) [5], Frost filter (Frost et al 1982) [6] and other despeckling algorithms were tried to filter the noise effectively with less computation complexity. In these types of filtering the image details are not effectively preserved resulting in blurred edges. Also, single scale representation of a signal either in time or frequency is inefficient as it is difficult to differentiate signal from noise. Also these kinds of filters are not recommended for non-stationary scene signal. However it is still an unsolved problem and there is no comprehensive method that solve all the constraints taken into consideration. Transform domain filtering of speckle were introduced to overcome these limitations.

Previously the despeckling concept of SAR images by using Wavelet transform (Portilla et al 2003, Xie et al 2002, Dia et al 2005, Ranjani et al 2010 [7]-[10], Curvelet Transform (Schimitt et al 1999, Candes et al 1999, Candes 2004,Starck 2002) [11] –[14] and the combination of these two domains (Saevarrson et al 2004) [15] were performed. The Wavelet transform is basic and efficient tool that acts on the denoising of SAR images because of its properties of time-frequency localization, multi-resolution, sparsity and decorrelation it exhibits good performance in despeckling but some artifacts occur during filtering and also it is not directional. Another disadvantage in Wavelet domain is that it identifies only point discontinuities and not able to diagnose the direction of any line shaped discontinuity in the image. Then Contourlet transform was applied because of its special characteristics of multi-resolution, multidirectional and speedy operation which addresses the problem of wavelet transform (D0 et al 2005) [16]. The combination of Wavelet and Contourlet transform was experimented in despecklng of images (Saevarrson et al 2004) [17]. The extension of this is carried over by Bandelet transform (Zhang et al 2009) [18], followed by the other multi-scale analysis experimented with Ridgelet transform. The Ridgelet transform is only suitable for discontinuities along straight line and not optimal for complex images where the edges were mainly along curves. Hence the feature enhancement is carried out and experimented with Curvelet domain.

The remainder of this paper is organized as follows: Firstly, in section II, the review of the Curvelet transform is described followed by the explanation about the Feature enhancement of SAR images in section III. Next the Result and Discussion is dealt in section IV and finally in section V, the paper ends with conclusion.

2. THE CURVELET TRANSFORM

The limitations of spatial filtering in speckle removal process is overcome by Transform domain filters with edge preservation .

The preservation of edges should be definitely made while despeckling of SAR images. The Curvelet overcome the problem of applying Wavelet transform, Contourlet transform and Bandelet transform in despeckling. The Curvelet transform is very efficient in attaining enhanced edges in an image by modifying its Co-efficients. The Curvelet transform was introduced by Candes and Donoho in 2000 and involves the analysis of step by step procedure in Ridgelet transform. This process is slow and researchers develop a new version by discarding the preprocessing step of Ridgelet transform so that the redundancy of the transform is reduced with improvement in speed. Another importance of Curvelet transform is that it needs only less co-efficients for representation producing a smoother edge than Wavelet edge (Bouchair 2005) [19]. Curvelet transform is considered to be the latest development among non adaptive transforms. It provides more space representation of the image with inspired directional elements. It has better ability in representing edges and other singularities along curve than Wavelet transform. Also Curvelet have good geometric feature and variable anisotropy.

The Curvelet transform is implemented based on wrapping of Fourier samples. 2D image is taken as an input in the form of a Cartesian array, f(m, n) when $0 \leq x < M$, $0 \leq y < N$ where M and N are the dimensions of the array. As illustrated in Eq.5 , the output will be a collection of Curvelet co-efficients $C^d(p,q,k_1,k_2)$ indexed by a scale ‘p’, an orientation ‘q’ and spatial location parameter k_1 and k_2..

$$C^d{}_{(p,q,k_1,k_2)} = \sum_{\substack{0\leq x<M \\ 0\leq y<N}} f(x,y)\ \emptyset^d{}_{(p,q,k_1,k_2)}\ (x,y) \qquad (5)$$

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Each $\emptyset^{d}{}_{(p,q,k_1,k_2)}(x,y)$ is a digital Curvelet waveform and'd' represents digital.

With these approach the effective parabolic scaling law on the sub bands in the frequency domain to capture curved edges within an image are implemented in more effective ways. From Fig.1 it is seen that the Curvelet becomes fine and smaller in spatial domain and shows more sensitivity to curved edges as the resolution level is increased thus allowing to effectively capturing curves in an image and curves singularities can be well approximate with fewer co-efficients.

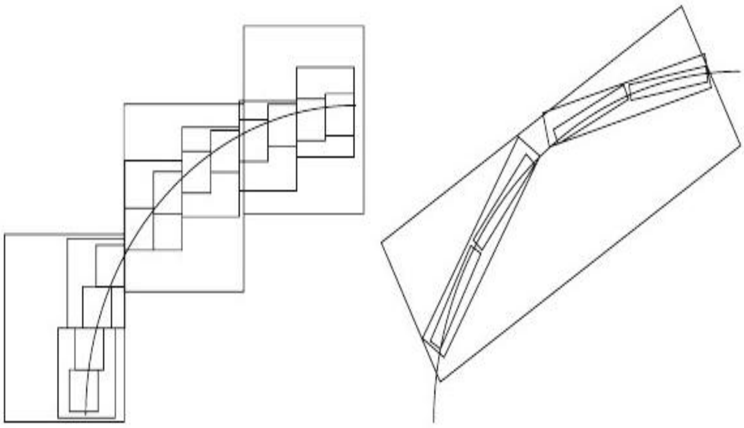


Fig.1 An Approximation comparison of (a) Wavelet and (b) Curvelet

The Curvelet itself will not have the ringing and radial stripe but will appear in the threshold value denoising process. It is a high dimensional generalization of the wavelet transform designed to represent images at different scales and different angles. Curvelets are superior to wavelet by sparse representation in object with edges optimal image reconstruction.

3. FEATURE ENHANCEMENT OF SAR IMAGE

3.1 Improved Gain Function

The co-efficients of the curvelet transform are shrinked and stretched to achieve the improved gain function. Then thresholding is applied to despeckle the image by replacing each pixel in an image depending upon the pixel image intensity level referring the fixed constant called threshold. Here the pixel value is set to zero, if a Curvelet sub band coefficients are smaller than a predefined threshold; if not, the absolute value shrinks by the value of threshold. This function is known as Soft thresholding. Same as soft thresholding, if a Curvelet 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 process is carried out.

Starck et. al (2002) [20] introduced image despeckling using hard thresholding of Curvelet co-efficients represented in Eq. 6 and then Starck et. al (2003) [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,

$$k_{a(i,j)} = \begin{cases} 1 & , if\ i < aj \\ \frac{i-aj}{aj}\left(\frac{n}{2aj}\right)^x + \frac{2aj-i}{aj} & , if\ aj \le i < 2aj \\ \left(\frac{n}{i}\right)^x & , if\ 2aj \le i < n \\ \left(\frac{n}{i}\right)^y & , if\ i \ge n \end{cases} \quad (6)$$

where j = standard deviation of noise

x = the degree of non- linearity

y = the dynamic range compression

a = the parameter of normalization

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 in the gain function hard thresholding is applied to enhance the features of SAR image by simultaneously suppressing the speckle by modifying the gain function as in Eq. 6 to Eq. 7 as,

$$k_{a(i,T)} = \begin{cases} 0 & , if\ i < T_1 \\ \frac{i-T_1}{T_1}\left(\frac{T_3}{T_2}\right)^x + \frac{T_2-i}{T_1} & , if\ T_1 \le i < T_2 \\ \left(\frac{T_3}{i}\right)^x & , if\ T_2 \le i < T_3 \\ \left(\frac{T_3}{i}\right)^y & , if\ i \ge T_3 \end{cases} \quad (7)$$

The main disadvantage in the improvement of gain function is to properly selecting the parameters T_1,T_2,T_3, x & y.

3.2 Optimization Technique in Image Enhancement

Firefly Algorithm (FA) was developed by Xin-She Yang (2007) [22] at Cambridge University. FA is an optimization algorithm inspired by the behavior and motion of fireflies. Farahani Sh et al (2011) [23].

Numerous firefly species occupied in the sky produce short and rhythmic flashes in the moderate temperature region. Mostly specific species produce specific pattern. The attraction male and female species produces a kind of pattern depends upon many factors like the rhythm of the flashes, flash rate and the flash time. The communication of fireflies with each other is limited 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 unique in sex, so one firefly is attracted to other firefly irrespective of their sex.

- Attractiveness and brightness changes with 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 the attractiveness increases with their distance decreases. If the brightness of All fireflies move randomly if their brightness are same.
- The objective functions determine brightness of a firefly.

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

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

$$p_i = p_i + A_o e^{-\gamma d_{i,j}^2}(p_j - p_i) + \propto \epsilon_i \quad (8)$$

where, $A_o\ e^{-\gamma d_{i,j}^2}(p_j - p_i)$ 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 $\propto \epsilon_i$ [0, 1]. The behavior of the fireflies is determined by the important paramaeter γ. 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.

3.4 *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. 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.

3.5 Proposed Methodology of Despeckling and Enhancement of SAR images

The despeckling and enhancement algorithms used for SAR images can be explained as step by step procedure and it is shown in Fig. 2.

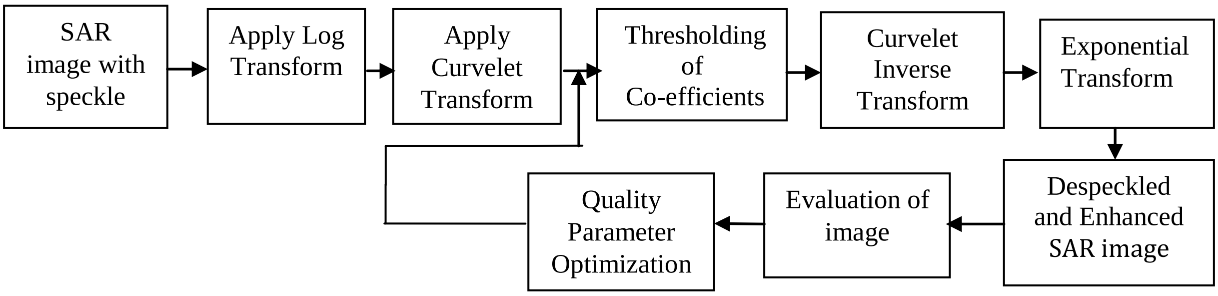


Fig. 2 Block diagram of the proposed despeckling and enhancement of SAR image.

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 Eq.2. where 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 Curvelet transform to $I'_{(m,n)}$ up to 'n' levels and 'm' directional decomposition at each level the Curvelet co-efficients are achieved.
- Then thresholding of Curvelet 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 Curvelet sub band coefficients 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 Curvelet 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 despeckling by removing the unaccepted values less than threshold value. Here hard thresholding is applied.
- Apply the inverse Curvelet transform on the threshold image and then exponential transformation is carried over to obtain the despeckled image.
- The parameters for the despeckled image are computed.
- Each despeckled and enhanced image is evaluated using evaluation function.
- Repeat the steps till the stop condition of the Firefly Algorithm is satisfied.

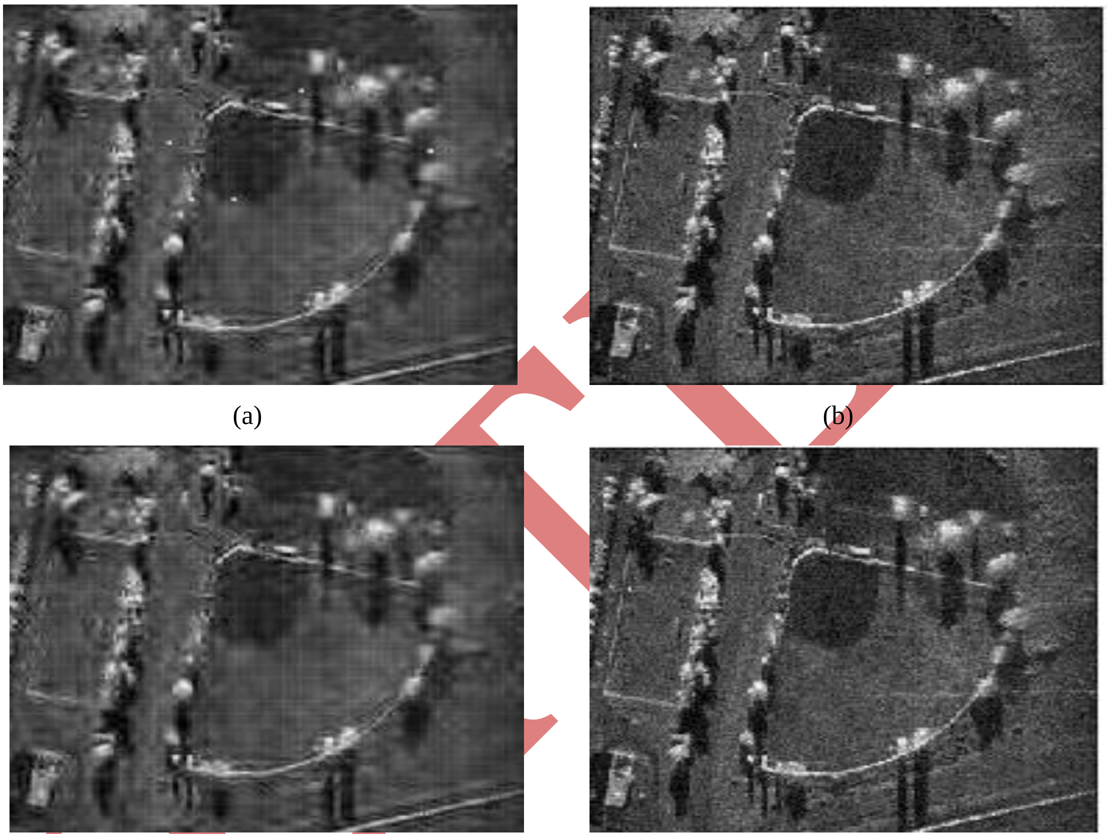
. The procedure is repeated with Wavelet transform with FA and the results are compared.

5.RESULT ANALYSIS AND DISCUSSIONS

In this section, analyses of simulated results of despeckled SAR images are presented. The comparison with the experimental results about despeckling of SAR images with Wavelet domain and Curvelet domain both optimized using Firefly Algorithm are done. Three Noisy images say, the Baseball Diamond, Kirtland, Govan, Scotland and Pentagon, United States are taken for experimental purpose. Despeckling of these images were done using different transform domain filter with Firefly Algorithm and also compared with the results of previous method of Modified Particle Swarm Optimization (MPSO) (Shanthi et al 2013)

Case (i)

For analysis, the Baseball Diamond, Kirtland SAR image is investigated. The MATLAB tool was applied for simulation purposes. Fig.3(a) and (b) represent the despeckled images of Baseball Diamond using Wavelet and Curvelet with Modified Particle Swarm Optimization (MPSO) and 3(c) and 2(d) show the despeckled images using Wavelet and Curvelet with Firefly Algorithm (FA) respectively after the despeckling process.



(a) (b)

(c) (d)

Fig.3 Despeckling and Enhancement result of Baseball Diamond SAR image. a. Wavelet with MPSO b. Curvelet with MPSO c.Wavelet with FA, c. Curvelet with FA.

From the simulated results it is clear that the fine details of the image is lost in Wavelet domain filtering with MPSO by blurring the image. Also it shows that Curvelet transform with MPSO performs better than Curvelet transform with FA yields the best result in enhancement of feature details of the image after despeckling.

To measure the performance of Despeckling, the different Quality metrics of the despeckled image are evaluated and tabulated in Table.1 for the Baseball Diamond SAR image. It shows the simulated result of different parameters like MSE, ENL, SSI, SMPI, ESI_ H, ESI_V and PSNR for comparison.

Table 1: Comparison of performance of Wavelet transform and Curvelet transform with Modified Particle Swarm Optimization and Firefly Algorithm for the SAR image of the Baseball Diamond, Kirtland.

Image	Quality Parameters	WMPSO	CMPSO	WFA	CFA
Baseball Diamond	MSE	**0.404**	**0.00043**	**0.0057**	**0.00031**
	ENL	4.5799	4.6085	6.2832	4.5385
	SSI	1.0034	1.0003	0.8598	1.0676
	SMPI	1.1022	1.0203	0.8591	0.9568
	ESI-H	1.0002	1.0000	0.0843	0.8799
	ESI-V	1.0000	1.0000	0.6483	1.0000
	PSNR	**61.7591**	**81.7862**	**70.5552**	**82.6181**

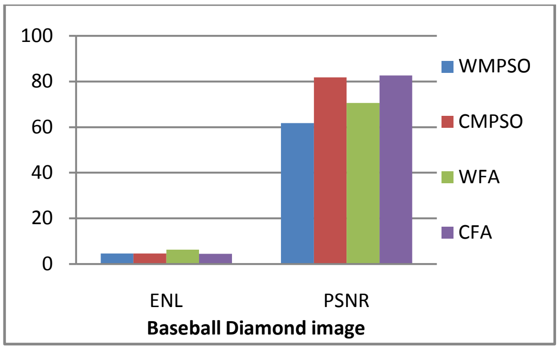
From Table.1 it is seen that the Mean Square Error (MSE) is much reduced from 0.404 to 0.00031 by denoising the image using Wavelet with MPSO to Curvelet with Firefly Algorithm by referring the Eq.9 as,
For any two images x and y [F and G], if one image is considered to be the noisy approximation of the other, the Mean Square Error is defined as,

$$MSE = \frac{1}{xy}\sum_{m=0}^{x-1}\sum_{n=0}^{y-1}[F(m,n) - G(m,n)]^2 \quad (9)$$

Again the comparison is made for the Quality parameter Peak Signal to Noise Ratio (PSNR) which measures Signal against Noise present in the resulting denoised image.The quality of the image after despeckling is evaluated by this factor PSNR which can be defined in Eq. 8 as,

$$PSNR = 20\log_{10}\left(\frac{MAXi}{(\sqrt{MSE})}\right) \quad (10)$$

If Max_i^2 is considered as Maximum Intensity of noisy image and MSE is Mean Square Error then the higher quality image is obtained if PSNR value is higher. By referring the Table.1 it is confirmed that the PSNR of the despeckled image is very much improved from 61.7591 using Wavelet with MPSO to 82.6181 using Curvelet with FA. The filter performance of Baseball Diamond SAR image with Quality parameters are presented in Fig.4.



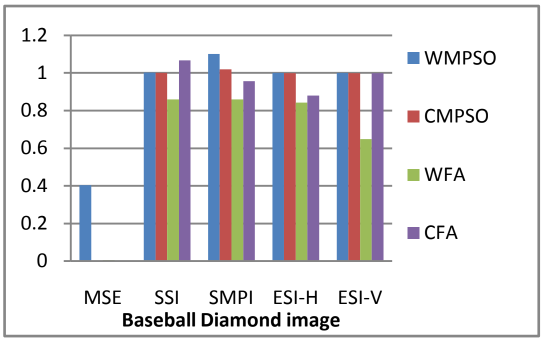
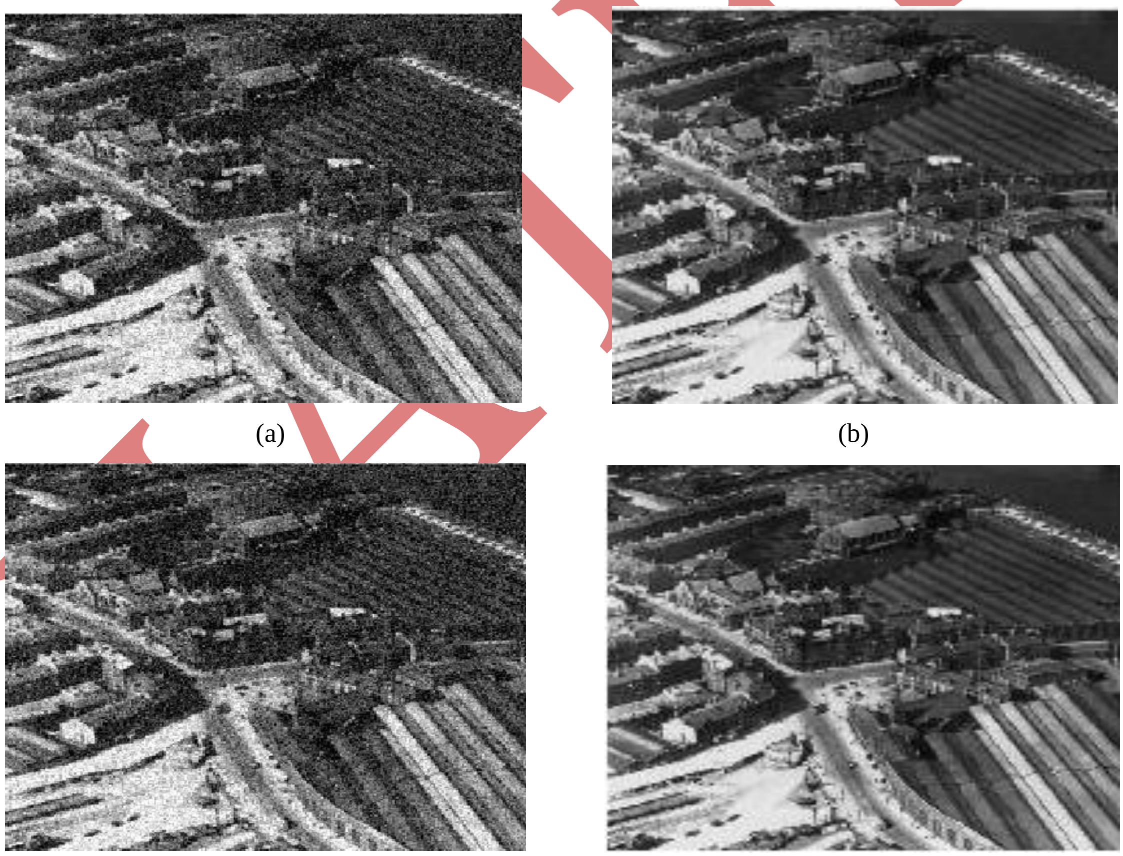


Fig.4 Filter performance of Baseball Diamond SAR image against Quality parameters

The feature enhancement of SAR image was resulted by despeckling noisy image.

Case (2)

The investigation was done on the Govan,Scotland SAR image. The simulated results as images after despeckling using different transform domain with different algorithms were shown in Fig. 5 and represented the evaluated of Quality parameters of the despeckled image in Table.2.



(a) (b)

(c) (d)

Fig.5 Despeckling and Enhancement result of Govan, Lanarkshire SAR image. a. Wavelet with MPSO b. Curvelet with MPSO c.Wavelet with FA, d. Curvelet with FA.

From Fig. 4 it is seen that the despeckled Govan, Lanarkshire SAR image using Curvelet with Firefly Algorithm outperforms in showing the fine details of the image with its edges than the other techniques implemented in despeckling. The performance of despeckled image is evaluated by its Quality parameters. The simulated result of Quality parameters using MATLAB tool is shown in Table.2.

The PSNR is raised to 84.1405 using Curvelet transform with FA from 57.9749 using Wavelet with MPSO technique. Also the MSE is very much decreased from 0.10367 to 0.00025.

The parameter Edge Save Index represents the preservation of edge details both in horizontal direction and vertical direction defined by,

The ESI parameter gives the ability to save the edges of the image while doing the despeckling both in Horizontal

(ESI - H) and in Vertical (ESI - V) directions given by,

The Edge save ability in Horizontal direction is given as,

$$ESI-H = \frac{\sum_{m=1}^{x}\sum_{n=1}^{y-1}|G(m,n+1)-G(m,n)|}{\sum_{m=1}^{x}\sum_{n=1}^{y-1}|F(m,n+1)-F(m,n)|} \quad (11)$$

$$ESI-V = \frac{\sum_{m=1}^{x}\sum_{n=1}^{y-1}|G(m+1,n)-G(m,n)|}{\sum_{m=1}^{x}\sum_{n=1}^{y-1}|F(m+1,n)-F(m,n)|} \quad (12)$$

where F is the original image

G is the reconstructed image

x – Number of rows in an image and

y – Number of columns in an image.

It is evident that the despeckling of Govan SAR image is improved with their edge preservation by referring the values shown in Table.2.

image	Quality Parameters	WMPSO	CMPSO	WFA	CFA
Govan, Lanarkshire	**MSE**	**0.10367**	**0.000981**	**0.0169**	**0.00025**
	ENL	2.2772	2.2363	2.3838	2.1287
	SSI	1.0023	1.0003	0.9272	1.0361
	SMPI	1.3161	1.0309	0.9263	0.9810
	ESI-H	1.0000	1.0000	1.3006	1.0004
	ESI-V	1.000	1.0000	1.2340	1.0003
	PSNR	**57.9749**	**78.2114**	**76.2555**	**84.1405**

Table 2: Comparison of performance of Wavelet transform and Curvelet transform with Modified Particle Swarm Optimization and Firefly Algorithm for the Govan, Lanarkshire SAR image.

Good noise reduction occurs when the Quality parameter Speckle suppression and Mean Preservation Index (SMPI) value is low. The SMPI parameter is utilized when ENL and SSI are not reliable when the filter overestimates the mean value. Here the SMPI parameter value is reduced using FA. The SMPI is defined by an Eq.13 as,

$$SMPI = H \times \sqrt{\frac{Var\,(G)}{Var\,(F)}} \quad (13)$$

where H = J + |Mean(G) – Mean(F)| and

$$J = \frac{Max\,(Mean\,(G)) - Min\,(Mean\,)G))}{Mean\,(F)} \quad (14)$$

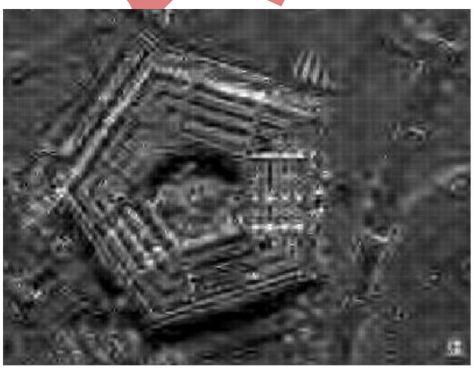
The performance of despeckling measured by its Quality parameters are represented as graph in Fig.6 showing that the PSNR parameter value is improved by reducing its MSE parameter value.

Fig.6 Filter performance of Baseball Diamond SAR image against Quality parameters

The feature enhancement is carried out with the Govan, Lanarkshire SAR image satisfactorily.

Case (3)

The Pentagon, United States SAR image is considered for analysing the the performance of despeckling Algorithm applied to filter the speckle noise present which degrade the image details. Fig.(7) shows the despeckled image of Pentagon SAR image tried for despeckling using different transform domain filters with different optimization techniques MPSO and FA to increase the presentation of lost fine details of the image due to presence of speckle.



(a)

(b)

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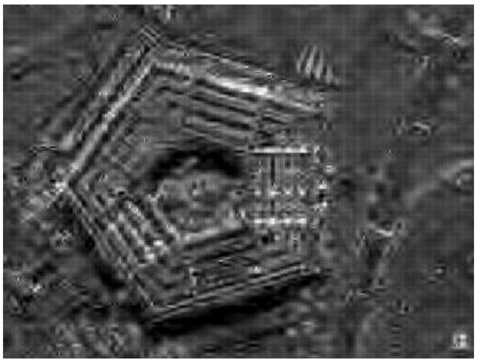


(c)

(d)

Fig.7 Despeckling and Enhancement result of Pentagon, United States SAR image. a. Wavelet with MPSO b. Curvelet with MPSO c.Wavelet with FA, d. Curvelet with FA.

The resulted different Quality parameters of the despeckled Pentagon SAR image were tabulated in Table.3.

Table 3: Comparison of performance of Wavelet transform and Curvelet transform with Modified Particle Swarm Optimization and Firefly Algorithm for the Pentagon, United States SAR image.

Image	Quality Parameters	WMPSO	CMPSO	WFA	CFA
Pentagon	**MSE**	**0.0962**	**0.00109**	**0.0105**	**0.000325**
	ENL	2.7091	2.7285	5.5845	3.3169
	SSI	1.0040	1.0005	0.7791	1.0641
	SMPI	1.3039	1.0326	0.7785	0.9507
	ESI-H	0.9996	1.0000	0.9236	0.9971
	ESI-V	0.9992	1.0001	0.9013	0.9970
	PSNR	**58.298**	**77.725**	**67.9113**	**83.0035**

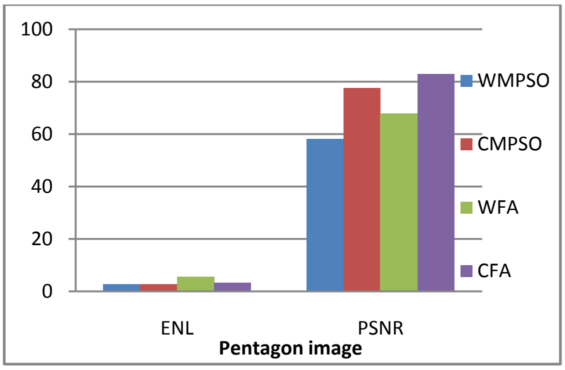
The tabulation concludes that the MSE value s very much decreased from 0.0962 using Wavelet with MPSO to 0.000325 using Curvelet with FA. Also the PSNR value is improved to 83.0035 using Curvelet with FA from 58.298 using Wavelet using MPSO. Also the Speckle Suppression Index (SSI) parameter is increased to 1.0641 which suppress the speckle more.

Speckle Suppression Index is given by an equation as ,

$$SSI = \frac{\sqrt{Var\,(G)}}{Mean\,(G)} \times \frac{Mean\,(F)}{\sqrt{Var\,(G)}} \quad (15)$$

where Var is the variance of the image.

The graphical representations of the Quality parameters are shown in Fig.8.



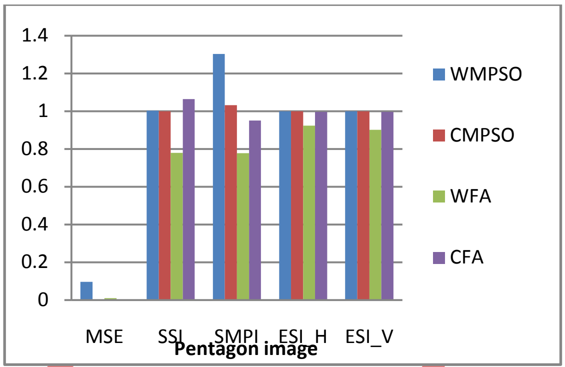


Fig.8 Filter performance of Baseball Diamond SAR image against Quality parameters

From the results and analysis, it is observed that after simulation, the combination Curvelet transform with Firefly Algorithm produces best result in despeckling when compared to other techniques adopted for all the three SAR images. The Quality metrics Mean Square Error (MSE) is much reduced and Peak Signal to Noise Ratio (PSNR) parameter is much improved in Curvelet transform with FA are observed. The simulation is carried over using MATLAB and the termination exists when maximum generation is reached.

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 non- linearly shrinking and stretching the co-efficients of Wavelet transform. The procedure is repeated using Curvelet transform with Firefly Algorithm. These results are compared with the previous method, by optimizing the Quality parameters with Modified Particle Swarm Optimization. The Firefly Algorithm is applied to make the speedy convergence and avoid premature convergence in optimizing the parameters. After the analysis of the results it is concluded that the Curvelet transform with Firefly Algorithm provide excellent performance of despeckling the simulated and real SAR images with feature enhancement. Our proposed method 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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