A Study Based On Various Performance Criteria of Filtering Techniques Used To Despeckle the SAR Imagery

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Abstract: The article presents a study based on the various performance metrics and compares the most frequently filtering techniques used for the purpose of removal of salt and paper type noise from SAR image. Since Synthetic Aperture Radar (SAR) imaging system has certain advantages over optical satellite imaging system so it is widely used in applications like oceanography, flood mapping, resource management, agriculture, surface deformation and etc. The main concern of analyzing the SAR images is the presence of speckle in the image under study due to the interference of dephased back scattered radiations. The unwanted information corrupt the quality of SAR images and thus formulate the observation and analysis of vital information difficult which is present in the SAR image. Therefore many filtering techniques or denoising techniques have been invented to reduce or remove the amount of speckle present in the SAR images. This paper presents the study based on various spatial as well as frequency domain filters developed so far alongwith commonly used qualitative parameters like MSE, PSNR, ENL, Speckle Suppression Index and etc used to analyze the SAR imagery.

Keyword: **SAR image, Speckle, Spatial domain filters, Wavelet transform, curvelet transform.**

I. INTRODUCTION

Remote sensing is a field of science that deals with the sensors to capture or measure the information (in the form of energy radiated and received) of earth's surface without making any direct contact with the target. Two types of sensors are used for remote sensing - Passive sensors and Active sensors. Optical remote sensing works on visible band and infrared band of frequency and uses passive sensors to record the energy reflected by Earth's surface which is generated by natural source (solar energy). While in microwave remote sensing, the electromagnetic energy is a transmitted and backscattered signal is received from the illuminated surface by active sensors. The radar usually work in the microwave band of the electromagnetic energy spectrum and uses active sensors in order to work independently in all-time conditions and with wavelength dimensions comparable to target.

Passive sensors have limitations like the absence of independent source of radiation and low performance during the presence of clouds or fog covering the area of interest. However, the difference between them is not only the presence of independent source but also in the acquisition way. Antennas and digital computer tapes are used by microwave sensing systems to collect the information, whereas camera lens and films are used by optical systems. Synthetic Aperture Radar (SAR) is an active remote sensing system used for imaging the earth's surface activities. It has become very valuable and popular with the launch of SEASAT (ocean satellite) in 1978. The major advantage of using SAR for imaging purpose is that it has its own source of light and energy. For imaging operations, it elucidates the earth's surface with the band of electromagnetic energy [1, 2]. In addition, it can run in all weather, day and night conditions thus gained advantage over optical satellite imagery system. SAR imaging system has wide range of application especially in forestry, oceanography, agriculture, flood mapping or monitoring , oil spilling, prediction and monitoring of natural disasters, soil monitoring, crop classification , terrain analyzing and etc. The developments in SAR lead this Radar systems to wrap large geographical areas [3]. So, to envelop large geographical area with high resolution imagery, a huge amount of data required to be acquired, stored as well as transmitted thus necessitates plenty amount of resources like channel capacity and storage media [4].

II. SPECKLE

All the coherent imaging systems like SAR imagery, laser and acoustics generally introduce the type of noise called speckle when forming the image. So, before interpreting the SAR images it is important to measure and analyse the amount of Speckle present in SAR. Speckle is the resultant of backscattered signals from the illuminated surface. The received signal is the outcome of the coherent sum or integration of every part of the return signals from the random scattering of the rough surface or inhomogeneity of the surface [1]. Due to the continues movement of the sensors, the received signal keep on changing with time. Granule called speckle appeared in the SAR imagery due to the fluctuations in the received signal ,which degrades the quality of SAR imagery. SAR imagery is multiplicative in nature, whereas in natural images (derived from optical sensors) is additive. The removal algorithms for additive noise requires less efforts, whereas multiplicative noise needs complex as it contains the backscattered signals. The multiplicative noise can be approximated as

$$Y(x,y) = O(x,y)N(x,y) \ldots\ldots\ldots\ldots\ldots (1)$$

In above equation, spatial locations variables represented by *x* and *y* whereas O(x,y) represents noise-free SAR original image, to be recovered and Y(x,y) represents the noise corrupted signal due to presence of N(x,y) multiplicative noise. Take the log transformation on both sides to separate the amount of noise from the original signal.

Shown below the result of log transformation

$$Y(x,y) = O(x,y) + N(x,y) \ldots\ldots\ldots\ldots (2)$$

As we know that mean of the log transformed signal is non zero so the resultant of log transformation produces undesirable effects in the SAR image. Addition of the Speckle noise generally affects the radiometric resolutions which are required for the interpretation of the produced SAR image and thus mandatory pre processing step to despeckle the SAR imagery for detection or classification optimization. First is Multi look integration and second is Adaptive image restoration (also called post- image formation) are the two major classifications of despeckling techniques. The L factor (number of looks) is the crucial criteria for Multi look integration technique. It reduces the speckle by reducing the azimuth spectrum but at the expense of high computational time and degrades the quality if the degree of L is too high. Therefo re many SAR systems satisfy with fewer numbers of looks in order to improve the image quality. If further required residual noise has to be removed using post image formation filters.

III. METHODS FOR DESPECKLING THE SAR IMAGES

The process of removing unwanted noise called speckle from SAR imagery is called despeckling. The quality of SAR imagery can be enhanced by selecting good adaptive image restoration technique for despeckling. Speckle filtering techniques have mainly three main objectives -Removal of noise or unwanted signal from uniform area, Preservation as well as enhancement of features like edges and texture without changing them and Preservation of radiometric parameters and the quality of visual appearance.Many schemes have been invented to despeckle the SAR imagery. The processing of SAR image can be done either in the spatial domain or in frequency domain by using wavelet transform. In Spatial domain the filtering is done by manipulating the intensity of neighboring pixel. This technique uses a rotating window which moves around the central pixel to vary the intensities of all the pixels within the window till whole image is covered. Image smoothening and sharpening, contrast augmentation are the few advantages of using this method but it has limitations over kernel or window size and no manipulation of frequency components. The transform domain based despeckling manipulates the frequency only and produces sharp images but it lacks in contrast management. Multi look is speckle reduction technique that gets the output after averaging a number of independent images or number of looks. The drawback of above is that computation level increases as number of looks increases, thus overhead increases.

IV. SPATIAL DOMAIN FILTERS

In spatial domain filtering manipulation of intensity of pixel is directly done by a rotating window that moves on pixel by pixel over the whole area of image and replace the value of central pixel by new calculated value. This section reviews some of the standard spatial domain filters like Lee, Frost, Enhanced Frost, Kuan, Median and Mean especialy used for speckle reduction in SAR images.

1. Lee et al.,[5] uses the neighborhood pixels value in the kernel. The local statistics of the pixel are taken into consideration when each pixel is processed independently. Minimum Mean Square Error (MMSE) is a performance metric used to measure weight function and is optimal when intensities are guassianlly distributed. This filter works well to suppress the noise over an area of high variance near the edges but it over smooth the details and ignore the area close to the edges and lines thus cause blurring effect in the image.

2 Frost filter,[6] is an averaging filter that uses the exponentially weighing factors within the kernel. The variance deceases with the decrease in weighing factor. The values of variance and mean are used to get minimum amount of MSE from homogeneous area. The smoothening effect is observed in high variance region while preserving the edge details in the image. It introduces the blurr effect in the image as it has limitations over uniform area while removing the noise. It only removes only few amount of speckles from the image thus degrades the quality of the image, but it has better Edge Preserving Ability (EPA) , SNR and PSNR. It is not optimal but is used for some applications.

3 Kuan algorithm [7] is an upgraded version of Lee' method as it does not make an approximation on the noise variance within the filter window. It is based on a Non stationary Mean and Non stationary variance image model that adapts to local changes during the measuring of image information statistics. This filter does not involve any perquisites of the image under study so, useful in removing the different types of noises while preserving the edge details of the image. The main drawback of using this filter is that it over smoothen the edges and details.

4 Gamma/MAP filter shows better performance over Frost as well as Lee for removing the amount of speckle in the images of forest area, agriculture land and ocean region as it minimizes the loss of texture information especially in images with Gamma Probability Density Function Model. Blurring effect in the image increases as window size increases[8].

5 Baraldi et al.[9], proposed a modified edition of Gamma Map called Refined Gamma Maximum A-Posterior that preserves the edges better than previous one. First it find the edges by making use of segmentation box and then apply filter box to each segment. Since it ignores the textural details thus produces blurred image.

6 In Mean or Average filter each pixel is replaced by the new calculated average value in the defined local neighborhood of filter window. Again the difficulty of introducing blurring effect in the image is the main hindrance of using this filter but it has advantage of removing noise with extra computation time. Median filter is a nonlinear filter that smoothens the image as well as smears the other details like edges. Moreover it is nonadaptive filters so, does not produce good result when applied on high density noise image. The other filters like moving average, Oddy, geometrical filters, performed better speckle reduction in homogenous area of SAR image but with some limitations like fixing the window size, degradation of resolution and smoothening of uniform area. The quantitative analysis of standard filters like Lee, Frost, Enhanced frost and Gamma Map was done on SAR image and the outcomes showed few tradeoff among reduction in speckle and preservation of meaningful information like edge and fine details.[10].

7 Srad filter[11] , an anisotropic diffusion technique based on an adaptive window has been developed for removing speckle in SAR imagery. In this method local variance of the pixels is calculated by an adaptive rectangular kernel having variable size and orientation. The window is varied in such a manner so that the pixels lying close to the edges have little impact on the pixels present on the edges. The technique produced good result for suppression of the speckle but at the cost of blur image.So to overcome the above described limitations, many researchers started working on frequency domain based filtering techniques which donot only preserve the information but also reduce the speckle upto certain extent.

IV. FREQUENCY DOMAIN FILTERS

These filters exhibit higher quality and better performance in reducing the speckle from SAR imagery as compared to the others, especially spatial domain filters. In this domain the frequency component can be manipulated to achieve high reduction of noise in image. Following is the study done on different frequency domain filtering methods ranging from Fourier transform to Short Fourier Transform and Wavelet transform to Curvelet transform with their merits and demerits. Unable to provide the information on time and frequency domain both simultaneously, Fourier Transform(FT) is replaced by Short fourier transform (SFT). But SFT came with the limitation of fixing the window size, thus not suitable for multi resolution analysis. So, a new transform called wavelet transform has been developed to overcome the above limitations and also proved to be good for MRA[12]. The wavelet transform allows the decomposition of signal into details and approximation coefficients. Typically the noise is presented by high frequencies and fourier transform tries to suppress the high frequency component but with the loss of edge details of the image. By selecting the proper shape of wavelet one can extract different linear feature and other details from the signal [13]. The wavelet domain provides best result for functions with discontinuities and sharp spikes. Both high and low pass filter sets along vertical and horizontal directions of image can be implemented by Discrete Wavelet Transform (DWT). Various types of thresholding methods like Bayesian,universal and wavelet threshold have been developed to manipulate the wavelet coefficients .Donoho suggested the use of wavelet thresholding or shrinkage method in denoising the image by selecting the wavelet coefficient against the threshold value. If the selected wavelet coefficient value is smaller than the set value of threshold, it is set to zero, otherwise one as in case of hard thresholding or can be modified in case of soft thresholding[14] . The wavelet shrinking method has a major drawback that it produces the artifacts and modifies the pixel value when wavelet coefficients are set under zero.[13]. The result of all thresholding techniques when compared with the result of spatial domain filters and it is found that these techniques proved effective in speckle reduction but fail to preserve edge details[15]. Another alternative to Discrete wavelet transform (DWT) is wavelet packet transform and stationary wavelet transform that showed high rate in suppressing the high frequency component called noise but at the cost of high computation time. Typically for SAR imagery, the use of orthogonal wavelet domain also showed significant improvement reducing the speckle when given to orthogonal DWT. Once all the parameters are selected , Inverse DWT is computed to build the reconstructed image. The major drawback lies in selecting the decomposition level. As the decomposition level increases computational complexity increases and produces more blur image. A new approach called spatially adaptive shrinkage factor is suggested , which involves less computation but does not able to preserve the other details of complex image [16]. A comparative analysis was done for shift invariant and filtering of signals by complex wavelets. Dual tree wavelet filter is used to calculate Complex wavelet coefficients , which has certain advantages over traditional wavelet transform. The limitation of using DWT is that it loses information while translating the original signal into subbands and also there is lack of symmetry of mother wavelet. Dual Tree Complex Wavelet Transform (DTCWT) has advantages of good directional selectivity, limited redundancy, fine shift invariance, less computational complexity, perfect reconstruction and less time to save the coefficients over DWT [17].As the results of Denoising by thersholding techniques are not successful due to the independence nature of wavelet coefficients, a new method is developed which is an extension of wavelet transform in many directions. Directionlet transform divides the image into many directions. Firstly calculating Independent closets and then perform transformation in different directions leadss better visual quality and preserve edge details [17]. Another approach which is a blend of undecimated wavelet transform (UDWT)and one of the adaptive filter like wiener or mean filter is suggested [18].As UDWT requires more space and computational time while saving the wavelet coefficients, so new makeover called Dual tree complex wavelet transform (DTCWT) is developed that produces many effect of complex coefficients. Real part as well as imaginary part of the complex wavelet coefficients is produced by different trees of DTCWT at each level. Since producd coefficients are said to be orthogonal as they are not related to each other. This resulted in providing the good directional selectivity , shift invariance and better edge details[19]. Because of performing well in multiresolution and sparse analysis, wavelet has proved many uses in image processing applications such as image edge enhancement, texture analysis, compression in addition to noise reduction. But it has limitations for line and surface singularities present in natural images, because natural images have more edges or discontinuities across curves[20]21][22]. This presents the need of curvelet transform.

Curvelets can provide the better solution than wavelet in curved singularities representation as well as it provides multiscale and multiorientation features. Curvelet is an anisotropic transform with a high degree of directionality and very few coefficients are required to represent the image. Location, scale and orientation are the parameters for indexing the frame elements in curvelet transform[23]. A smaller amount of nonzero coefficients is involved to represent the image edge for curvelet transform, and thus curvelet generates smooth edge than wavelet. The limitation of using this approach is that it shows poor performance and artifacts are produced when noise is high.

V PERFORMANCE METRICS

Several performance criteria suggested in the review of Qiu et al [24]. to assess the competency of various filters to remove or reduce the speckle and preserve the other details present in SAR imagery. Some measures evaluate the filters on the basis of speckle suppression ability, some on the basis of preservation of detail information and others on maintenance of mean value of distributed target. The outcomes of all criteria can be conflicting, thus a better and optimum solution to achieve different objectives and can be found with the help of using different criteria. It is also observed that along with these quantitative measures, one can also select qualitative visual inspection as comparative parameter of various filters for better results.

1. Speckle Suppression Index (SSI) mainly used to measure speckle strength which usually remains constant over the uniform area. The SSI is defined as $\left(\frac{\sqrt{Var(Rf)}}{Mean(Rf)}\right)..\left(\frac{Mean(Ro)}{\sqrt{Var(Ro)}}\right)$ …………(3)

where R*f* represents the filtered and R*o* is original image value. As speckle is removed to some extent in filtered image therefore it shows less variance as compared to the original image. Smaller the value of SSI (less than 1) greater will be speckle reduction.

2. Speckle Image Statistical Analysis (SISA) like mean and standards deviation which can be calculated from the ratio of original image and filtered image that represents the amplitude of amount of speckle. The resulting speckle image can be represented by SP=R*o*/R*f*. Closer the mean value of a filter to 1.0, better is the capability to retain the original value of an image. Standard deviation which is inversely proportional to SSI, is also another evaluator to judge the capability of a filter.

3. Speckle Suppression and Mean Preservation Index (SMPI) The two measures named ENL and SSI sometimes do not produce reliable results as they overestimate the mean value. So, SMPI is developed by Shamsoddini and Trinder, 2010 whose equation is given as $QX\left(\frac{\sqrt{Var(Rf)}}{\sqrt{Var(Ro)}}\right)..$ ……………..(4)

and Q=1+|mean(R*o*)-mean(R*f*) |. As mentioned above it is indicated that lower the value of SMPI better is the presentation of filter especially in terms of noise reduction and mean preservation in SAR imagery.

4. Edge Enhancing Index (EEI) is an another aspect to evaluate the filter for preserving the edge details of an image and defined as $\left[\frac{\sum(Rf1-Rf2)}{\sum(R1-R2)}\right]$ ………………………..(5)

where R1, R2 are the original and Rf1 and Rf2 are corresponding values of the filtered values of the pixel on either side of the edge. The higher value of EEI indicates the high ability of filter to preserve the edges.

5. The **Mean Square Error (MSE)** is the one of the most commonly used parameter that calculates a pixel by pixel value of the image. It is mostly used image fidelity parameter, because of its mathematical simplicity and ease of computation. **Peak Signal to Noise Ratio (PSNR)** is also one of the commonly used fact that measure the quality of reconstructed or compressed image in terms of signal . The higher the PSNR, better is the quality of a compressed image, can be expressed as

$$PSNR = 10\log_{10}\frac{(2^R-1)^2}{MSE}db = 20\log_{10}\frac{2^R-1}{RMSE}db$$, ………………………(6)

where 2^R-1 is the maximum gray level number. Calculating the Equivalent Number of looks (ENL) prove to be an another way to find the amount of speckle or unwanted noise in SAR image, using different values of pixel intensity over homogeneous area. It can be written as

$$\left(\frac{mean}{standard..deviation}\right)^2 \qquad \text{..}(7)$$

Since ENL carries no information regarding resolution degradation thus it is used with Signal to Mean Square Error Ratio as

$$\left(\frac{S}{MSE}\right) 10\log_{10}\left[\frac{\sum_{pixels} I1^2}{\sum_{pixels}(I2 - I1)^2}\right] \qquad \text{....................................}(8)$$

where I1 and I2 represents the despeckled and speckled image, corresponds to the standard SNR[25].

VI. CONCLUSION

The paper presented a study of spatial as well as frequency domain filters based on various performance criteria used for to evaluate the presence and reduction of speckle or noise in SAR imagery. The main aim of the filter study is to reduce the speckle while keeping the edge preservation details, image enhancement and image smoothening in a better way. The performance of Spatial filters depend on the size of window and wavelet based depend on the level of decomposition. As size or level increases blur effect also increases. So, in many cases it is a balance between these above factors which decide the selection of speckle removal filter. In conclusion, the combination of above filters can be considered to be the best technique to accommodate the tradeoff among less computation complexity, sufficient speckle suppression and edge preservation or detail retention.

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Mrs. Sakshi has completed her graduation, B. E Electronics from D.Y Patil College of Engineering, Kolhapur, Shivaji University in 1998 and M. S. Software Systems from BITS, Pilani in 2002. She is pursuing her research work in area of Image Processing from . She is working as Assistant Professor in Electronics and Communication Engineering Dept. at Dronacharya College of Engineering, Gurgaon, India. She has been in engineering teaching from 1998. Her recent work is concentrated in the area of SAR Image compression and denoising. She has 5 research conference and journal papers to her credit.

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