A Comparative study of Pre-processing Techniques of SAR Images

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***Abstract*--Synthetic Aperture Radar (SAR) images are high resolution images which are captured by remote sensors mounted on platforms like satellites, helicopters and planes. Electromagnetic waves are transmitted and the echoes reflected from the surface of earth are collected, by the sensor. The quality of image is deteriorated because of the speckle noise which is a type of multiplicative noise which arise due to variations in backscatter from non-homogeneous cells. The classification of images become difficult as the speckle noise manipulates the statistics of backscatter. It has undesirable effects on Automatic Recognition System(ATR) hence speckle filtering has become the first essential step for SAR image processing such as segmentation and edge detection. This paper presents a survey of various speckle filtering techniques highlighting the key features of each filter. It also lists the filtering criteria and performance statistics that should be used to check the performance of filter.**

Keywords--SAR, Image Pre-processing, filtering, frequency domain, spatial domain, noise, wavelet transform

I. Introduction

In the most recent years, satellite imagery has offered a new horizon for scientists monitoring earth environment and ecosystems as satellites orbiting the earth can gather all sorts of information about earth. The SAR imaging RADAR mounted on ERS-1 and ERS-2 satellites produce high resolution quality images of coastal zones, oceans, polar ice, land surface. This RADAR has all weather day and night capability and is not affected by cloud coverage. The images are captured y measuring the reflected radiations of micro-waves which bounce back from the earth surface. [12]. There are a wide range of applications of SAR images. It acts as a useful remote sensing tool for military and civilian users. The most important applications cover oceanology, glaciology, topography, geology and forestry. Differential interferometry includes volcano and earthquake monitoring. It also has many useful applications in the area of environmental monitoring mainly covering oil spills, floods, urban growth and global change. It can even be implemented as inverse SAR for automatic target recognition by observing a moving target using a stationary antenna.

SAR images are deteriorated by the speckle noise during image capture and transmission. It is a type of multiplicative noise which appears due to the variation in the backscatter from non-homogeneous cells which gives a grainy appearance to SAR images [1]. The backscatter is the result of constructive and destructive interference of the microwave radiation in resolution cells. Many different methods have been discussed in literature to eliminate speckle noise. The errors in the captured image is mainly related to geometry and intensity of pixels. These errors are reformed using definite or statistical mathematical models. Image enhancement aims to modify the image to improve the visual impact and convert the image in a form that can be interpreted by human or machine. The enhancement process only focus on certain specified characteristics of an image to find the important features which will be helpful in performing classification[2]. Hence, it is useful in feature extraction, image analysis and an image display. The next section explains in details the two broad categories of filtering frequency domain filtering and Spatial filtering.

II. The most prevalent Pre-processing techniques for SAR images

The pre-processing techniques of SAR images have been broadly put under following two categories: Frequency Domain Filtering and Spatial Filtering. Under Spatial filtering, we have the following 3 techniques: Contrast Stretching, Noise filtering, and Histogram modification. Under Frequency domain filtering we have Fast Fourier Transform and Wavelet Transform. The following subsections take a deeper look at these categories. Frost Filter technique, Gradient based adaptive median filter, The Wavelet Coefficient Shrinkage (WCS) filter, Discrete Wavelet Transform (DWT), enhanced Lee filter, wiener filter and fuzzy filter in wavelet domain, Time Reversal SAR (TRSAR), image formation techniques, Statistical modelling, Dark channel technique, also into above 2 broad categories. Some of the enhancement techniques are:

A. SPATIAL FILTERING

Spatial filtering is an important technique to process images and is mostly used as the preliminary step in a wide variety of image processing applications. It involves implementation of convolution filtering in the spatial domain. A moving mask (also known as kernel or neighborhood) of a small rectangular grid of pixel locations is moved on an image pixels one by one filtering out only those pixels which come within the mask. The output of this filtering is an intensity value which is used as an new intensity value for the pixel at the center of the mask. This method is replayed for all pixel in the image.

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This subsection describes the techniques involved in spatial filtering:

1) Contrast Stretching

The measure of the spread of Histogram is termed as a contrast of an image. It makes the object distinguishable from other objects and is calculated by subtracting the maximum pixel value and the minimum pixel value. It improves the quality of the image by stretching the range of the intensity values. The images which contain water bodies, dense forests, snow clouds etc do not have much change in gray levels and very narrow peaks are seen during histogram representation of such images. It is restricted to a liner mapping of input to the output values.

2) Gamma Corrections

The brightness of an image ranges between 0 to 1 where 0 denotes complete darkness (black) and 1 denotes brightness (white) of an image. Gamma correction is one of the methods which is used to control the brightness and correctness of an images.[2]

3) Log Transformations

Log transformation is generally used for the type of images which have input grey level values with extremely large range of values. A wider range of output values is mapped to a narrow range of low input grey values enhancing the quality of image [2].It is defined as:

$$s=c*log(1+c)$$

where c is usually 1.

4) Histogram Modification

The Histogram of an image is a graphical representation of the intensity of each pixel in the image. The characteristic of the image can be changed by the modification of the Histogram and can be achieved by the following techniques:

a) Histogram Stretching

It improves the contrast of image and is similar to contrast stretching.

b) Histogram Equalization

This techniques redistributes the pixel values in such a way so that same number of pixels come within a particular range resulting in a flat Histogram. This increases the contrast at the peaks and lessen at the tails.

B. FREQUENCY DOMAIN FILTERING

Filtering of the image could be done on a pixel of an image but it's easy to transform images in frequency domain as it involves matrix multiplication of only kernal and image in O(n2) time instead of a convolutional with the kernal which takes o(n4) time.

1) Fast Fourier transform

It is an important frequency domain filtering tool which decomposes an image into values of sinθ and cosθ. These point image are mapped to a definite frequency value. For filtering these images DFT tool is applied on the image transforming it into set of samples describing the image in the spatial domain.

The shifting of the image is done in such a way that the DC values are displayed on the image centre. The frequency is higher for the image points that are away from the centre of the image.

2) Wavelet transform

Edge is the most important frequency information in an image. The adaptive selection of frequency bands are based on the characteristics of the signal. It is useful in filtering noise from multi-resolution images. The wavelet coefficients measure how closely correlated the wavelet is with each section of the signal. the noise filtering results for wavelet transform is better as compared to the Fast Fourier transform

C. Denoising of SAR images

In above image enhancement techniques, we discussed about noise filtering. This section will elaborate more on the noise filters and its types. After reading about the filters from the literature This is used as a filtration step to filter the unnecessary information in an image. Various filters like low pass, high pass, mean, median etc., are available . Multi-look processing and spatial filtering reduce the speckle noise from images. Multi-look processing is performed at the time of acquisition of low resolution images. It averages out the speckle noise by taking several "looks" at a target in a single RADAR radius. Average is incoherent. The single look processing is quite noisy Spatial filtering is performed after the acquisition of data.

We have found two broad classification of filters:

1) Adaptive Filters:

- Accommodate changes in local properties of terrain backscatter.
- Better to preserve edges and high detail in high texture areas.

2) Non adaptive Filters:

- Takes parameter of whole image
- Simpler to implement and require less computational power.

III. NEED FOR FILTERING

- 1. Speckle noise is a type of multiplicative noise which causes variations in backscatter from non-homogeneous cells.[1]
- 2. Effects texture based analysis of images by reducing the contrast of image.
- 3. Changes then spatial statistics of backscatter which makes classification difficult.
- 4.Improves ability to segment images due to better discrimination of objects in the scene..
- 5. It has undesirable effects on ATR Automatic Target Recognition systems hence speckle filtering has become an essential step for SAR image processing.

The below table gives an overview of the types of filters along with the filtering criteria

TABLE I. SPECIAL FILTERS USED FOR SAR IMAGE PRE-PROCESSING

FILTER	ABOUT THE FILTER	FILTERING FORMULA
FROST	--linear filter -- weighted averaging filter --filter response depends on the coefficients of variation which is ratio if Standard deviation to mean of noisy image -- The sharp features are preserved by high coefficient variation -- Behaves as average filter with low CV	$DN = \sum_{n\,x\,n} k\alpha e - \alpha\lvert t\rvert$ [3] k is a normalization constant α is $(4/n\sigma'^{2}).(\sigma^{2}/\bar{I}^{2})$ $\bar{I}$ is the local mean, σ is the local variance, σ' is image coefficient of variation, $\lvert t\rvert = \lvert X - X0\rvert + \lvert Y - Y0\rvert$ and n is the moving window size.[3]
LEE FILTER	-- linear combination of intensity of center pixel with average window intensity is computed for removing speckle noise. -- based on the minimum mean square error (MMSE).[2]	$F(t) = I(\bar{t}) + W(t)(I(t) - I(\bar{t}))$ [3] where $F(t)$ filtered image , $I(\bar{t})$ mean value of $I(t)$, $W(t) = 1 - Cv/\ CI$ (4) where Cv is the coefficient of variation of noisy image with standard deviation, and CI is the variance coefficient of noise-free image with standard deviation.[3]
KUAN Filter	-- Minimum Mean Square Error (MMSE) criteria -- Gaussian distributed intensities of scene and target makes this filter optimum to use	$W = \frac{1 - \frac{Cu}{Ci}}{1 + Cu}$ W= weighted function Cu= estimated noise variation coefficient Ci=variation coefficient of image
MEDIAN FILTER	-- spatial non-linear filter. --The centre pixel value is replaced by the calculated median value of the neighbors in the window. -- effective for short duration noise but ineffective for speckle noise.	$f(x,y) = (s,t)\epsilon S_{xy}\{g(s,t)\}$ where g(s,t) original image, Sxy: set of image coordinates
MEAN FILTER	-- simple filter[2] -- centre pixel is replaced by the calculated mean of neighboring pixels in window --good filter noise smoothening -- reduces detail and resolution.	$f(x,y) = 1/m * n\sum(s,t)\epsilon S_{xy}\{g(s,t)\}$ [3] where m.n is kernel windows size, g(s,t) original image, Sxy Rectangular coordinates of window.
WCS Wavelet Co-efficient Shrinkage	--based on Symmetric Daubechies (SD) wavelets -- better approximation at sampling points[5]	
DWT Discrete Wavelet Transform	--high-frequency components of the image are preserved. --decompose image into different sub-bands --Sharp image is achieved by intermediate stage to estimate high frequency sub band	
Gradient based adaptive median filter	--based on Non-linear fourth order PDEs. --fourth order partial linear equations are faster than second order partial linear equations on high frequency.	$\frac{\partial y}{\partial x} = -\nabla^{2}[c(\lvert\nabla^{2}u\rvert)\nabla^{2}u]$ where $\nabla^{2}u$ is Laplacian of the image u.[3]

The below table summarizes the list of the research findings in the area of pre-processing of speckled SAR Images.

TABLE II. PRE-PROCESSING METHODS FOR SPECKLE NOISE REMOVAL

Sr No.	Author Name	Title	Method and technology
1.	M. Mansourpour , M.A. Rajabi , J.A.R. Blais, 2006 [3]	"Effects And Performance Of Speckle Noise Reduction Filters On Active Radar And Sar Images" .	Frost Filter technique
2.	S.Manikandan, , Chhabi Nigam, J P Vardhani and A.Vengadarajan, 2011 [4]	"Gradient based Adaptive Median filter for removal of Speckle noise in Airborne Synthetic Aperture Radar Images"	Gradient based adaptive median filter
3.	L. Gagnon and A. Jouan ,1997 [5]	"Speckle Filtering of SAR Images - A Comparative Study between Complex-Wavelet-Based and Standard Filters"	The Wavelet Coefficient Shrinkage filter
4.	P. Karunakar, V. Praveen and O. Ravi Kumar,2013 [6]	"Discrete Wavelet Transform-Based Satellite Image Resolution Enhancement"	Discrete Wavelet Transform
5.	Deepika Hazarika etal,2015 [7]	"A Lapped Transform Domain Enhanced Lee Filter with Edge Detection for Speckle Noise Reduction in SAR Images"	Lapped orthogonal transform domain adaptive enhanced Lee filter
6.	Naman Chopra and Mr. Anshul Anand , 2014 [8]	"Despeckling of Images Using Wiener Filter in Dual Wavelet Transform Domain"	Linear wiener filter and fuzzy filter
7.	YuanweiJi n et al., 2007 [9]	"Time Reversal Synthetic Aperture Radar Imaging In Multipath"	Time Reversal SAR (TRSAR), image formation techniques
8.	Ismail Ben Ayed et al. , 2005 [10]	"Multiregion Level-Set Partitioning of Synthetic Aperture Radar Images"	Statistical modelling
9.	Duk-jin Kim, Scott Hensley, Sang-Ho Yun, and Maxim Neumann, 2016 [11]	"Detection of Durable and Permanent Changes in Urban Areas Using Multitemporal Polarimetric Uavsar"	Dark channel technique

IV. CONCLUSION

The SAR images captured by moving satellites have degraded quality as they are corrupted by speckle noise. To make SAR images suitable for image segmentation and feature extraction several preprocessing techniques need to be applied on those images to improve the image contrast. The various filters have been designed in literature to preprocess the speckle noise and give an output image which could be further used for image analysis and image segmentation. Out of all the speckle filters WCS wavelet based filter is the best among the filters as it performs well in low level noise as well as in higher speckle noise level.

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