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Performance of Speckle Noise Reduction Filters on Active Radar and SAR Images

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***Abstract* - Reduction of speckle noise is one of the most important processes to increase the quality of radar coherent images. Image variances or speckle is a granular noise that inherently exists in and degrades the quality of the active radar and SAR images. Before using active radar and SAR imageries, the very first step is to reduce the effect of Speckle noise. Most of speckle reduction techniques have been studied by researchers; however, there is no comprehensive method that takes all the constraints into consideration. Synthetic Aperture Radar (SAR) images are becoming more widely used in remote sensing applications. SAR uses microwave radiation to illuminate the earth's surface. The coherent microwave illumination, however, suffers from fading effects result in generating a multiplicative speckle noise that corrupts SAR images. Filtering is one of the common methods which is used to reduce the speckle noises. This paper compares six different speckle reduction filters quantitatively using both simulated and real imageries. The results have been presented by filtered images, statistical tables and diagrams. Finally, the best filter has been recommended based on the statistical and experimental results.**

***Keywords* - SAR, FFT, MAP, RADAR, DN.**

I. SPECKLE NOISE REDUCTION FILTERS

Radar waves can interfere constructively or destructively to produce light and dark pixels known as speckle noise. Speckle noise is commonly observed in radar (microwave or millimeter wave) sensing systems, although it may appear in any type of remotely sensed image utilizing coherent radiation. Like the light from a laser, the waves emitted by active sensors travel in phase and interact minimally on their way to the target area. After interaction with the target area, these waves are no longer in phase because of the different distances they travel from targets, or single versus multiple bounce scattering. Once out of phase, radar waves can interact to produce light and dark pixels known as speckle noise. Speckle noise in radar data is assumed to have multiplicative error model and must be reduced before the data can be utilized otherwise the noise is incorporated into and degrades the image quality. Ideally, speckle noise in radar images must be completely removed.

However, in practice it can be reduced significantly. Reducing the effect of speckle noise permits both better discrimination of scene targets and easier automatic image segmentation. Generally speaking, speckle noise can be reduced by multi-look processing or spatial filtering (Raney, 1998). While multilinking process is usually done during data acquisition stage, speckle reduction by spatial filtering is performed on the image after it is acquired. No matter which method is used to reduce the effect of speckle noise, the ideal speckle reduction method preserves radiometric information, the edges between different areas and spatial signal variability, i.e., textural information. As this paper focuses on the effect of spatial filtering, interested readers can refer to Raney (1998) for more information on multi-look processing techniques. The spatial filters are categorized into two different groups, i.e., non-adaptive and adaptive. Non-adaptive filters take the parameters of the whole image signal into consideration and leave out the local properties of the terrain backscatter or the nature of the sensor. These kinds of filters are not appropriate for non-stationary scene signal. Fast Fourier Transform (FFT) is an example of such filters. On the other hand, adaptive filters accommodate changes in local properties of the terrain backscatter as well as the nature of the sensor. In these types of filters, the speckle noise is considered as being stationary but the changes in the mean backscatters due to changes in the type of target are taken into consideration. Adaptive filters reduce speckles while preserving the edges (sharp contrast variation).These filters modify the image based on statistics extracted from the local environment of each pixel. Adaptive filter varies the contrast stretch for each pixel depending upon the Digital Number (DN) values in the surrounding moving kernel. Obviously, a filter that adapts the stretch to the region of interest (the area within the moving kernel) would produce a better enhancement. Mean, median, Lee-Sigma, Local-Region, Lee, Gamma MAP, Frost are examples of such filters. Studying the effects of these filters are the subject of this paper therefore they are studied in a bit more detailed in the next section.

1.1 Speckle Filtering

As implicitly mentioned above, speckle filtering consists of moving a kernel over each pixel in the image and applying a mathematical calculation using the pixel values under the kernel and replacing the central pixel with the calculated value. The kernel is moved along the image one pixel at a time until the entire image has been covered. By applying the filter a smoothing effect is achieved and the visual appearance of the speckle is reduced.

1.1.1 Mean Filter

The Mean Filter is a simple one and does not remove the speckles but averages it into the data. Generally speaking, this is the least satisfactory method of speckle noise reduction as it results in loss of detail and resolution. However, it can be used for applications where resolution is not the first concern.

1.1.2 Median Filter

The Median filter is also a simple one and removes pulse or spike noises. Pulse functions of less than one-half of the moving kernel width are suppressed or eliminated but step functions or ramp functions are retained.

Figure1.1
Original image

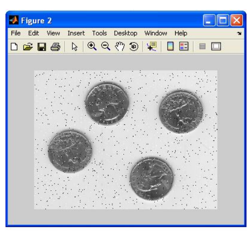

Figure 1.2
Median filter

1.1.3 Lee-Sigma and Lee Filters

The Lee-Sigma and Lee filters utilize the statistical distribution of the DN values within the moving kernel to estimate the value of the pixel of interest. These two filters assume a Gaussian distribution for the noise in the image data. The Lee filter is based on the assumption that the mean and variance of the pixel of interest is equal to the local mean and variance of all pixels within the user-selected moving kernel.

$$DN_{out} = [Mean] + K[DN_{in} - Mean] \quad (2)$$

where $Mean = average\ of\ pixels\ in\ a\ moving\ window$

$$K = \frac{Var(x)}{[Mean]^2 \sigma^2 + Var(x)}$$

and

$$Var(x) = \left(\frac{[Variance\ within\ window] + [Mean\ within\ window]^2}{[Sigma]^2 + 1} \right) - [Mean\ within\ window]^2$$

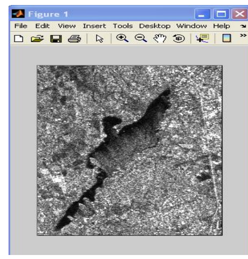

Figure1.3
Original image

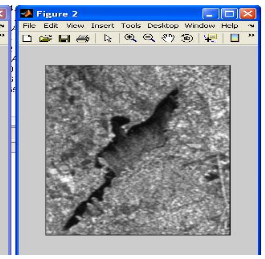

Figure 1.4
Lee filter with kernal size 3

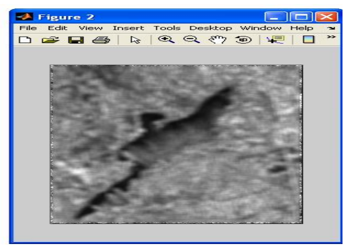

Figure 1.5
Lee filter with kernal size 7

COMPARATIVE ANALYSIS USING LEE SIGMA FILTER ON SAR IMAGES

KERNEL SIZE	MSE	SNR
3	86.0831	4.6405
5	85.9870	4.5856
7	85.27	4.5580

Table1.1

1.1.4.Gamma-MAP Filter

The Maximum A Posteriori (MAP) filter is based on a multiplicative noise model with non stationary mean and variance parameters. This filter assumes that the original DN value lies between the DN of the pixel of interest and the average DN of the moving kernel. Moreover, many speckle reduction filters assume a Gaussian distribution for the speckle noise. However, recent works have shown this to be invalid assumption. Natural vegetated areas have been shown to be more properly modeled as having a Gamma distributed cross section.

$$\hat{I}^3 - \bar{I}\hat{I}^2 + \sigma(\hat{I} - DN) = 0$$

where $\hat{I}$ = sought value
$\bar{I}$ = local mean
DN = input value
σ = the original image variance.

1.1.5.Frost Filter

The Frost filter replaces the pixel of interest with a weighted sum of the values within the nxn moving kernel. The weighting factors decrease with distance from the pixel of interest. The weighting factors increase for the central pixels as variance within the kernel increases. This filter assumes multiplicative noise and stationary noise statistics and follows the following formula:

$$DN = \sum_{n \times n} k\alpha e^{-\alpha|t|}$$

where $\alpha = (4 / n\bar{\sigma}^2)(\sigma^2 / \bar{I}^2)$
k = normalization constant
$\bar{I}$ = local mean
σ =local variance
$\bar{\sigma}$ = image coefficient of variation value
$|t| = |X\text{-}X_0| + |Y\text{-}Y_0|$, and

1.1.6 SRAD Filter

SRAD is Speckle Reducing Anti Isotropic filter. The size of the window is given much importance. Also direction is considered. By calculating MSE we get less value and SNR is very high.

II. SIMULATION RESULTS

The simulated imagery used for numerical experiment is a 227x167 pixel image with sharp edges (Figure1). A uniformly distributed multiplicative noise with mean zero and variance 0.05 is added to the simulated imagery. To test the efficiency of the filters mentioned above, at the first step a 3x3 kernel is used for the filters. All of the filters are applied to the noise contaminated imagery. Figure 2 shows the noisy as well as the filtered image using a 3x3 kernel. In order to evaluate the result of filters quantitatively, the following three parameters are defined and shows the comparison in the following table for all filters.

$$MSE = \frac{1}{K} \sum_{i=1}^{K} (\hat{S}_i - S_i)$$

where $\hat{S}$ = noisy image
S = original image
K = image size

Filter Type	*MSE*	*SNR*	β
Denoised Image	135.0792	23.0073	0.5389
Mean	91.5039	24.6988	0.7754
Median	152.9449	22.4679	0.7062
Lee-Sigma	53.4389	27.0347	0.8631
Local-Region	150.9129	22.5260	0.6940
Lee	45.9487	27.6905	0.8645
Gamma-MAP	20.5826	31.1782	0.9599
Frost	31.1305	29.3814	0.9096

Compared to other statistical filters, sigma-Lee filter introduces an acceptable compromise between speckle reduction and edge preservation. Comparing the proposed scheme with the best results of statistical filters (Lee-sigma) shows that, it surplus sigma-Lee filters in preserving fine details (ENL and DR), while sigma-lee has a slight improvement in variance values the proposed scheme has a promising results in reducing fading and speckles in radar SAR images since it is quite successful in constructing expansion systems (many other filters can be added the input image sequences) so as to give height sparsity and super resolution but at the coast of added computation and non linearity.

III. CONCLUSIONS AND REMARKS

Radar imageries are useful sources of information for roughness, geometry, and moisture content of the Earth surface. As an active, day/night, and all-weather remote sensing system, RADAR imageries can provide us information from both surface and subsurface of the Earth. Inherent with RADAR imageries is speckle noise which gives a grainy appearance to the imageries. Speckle noise reduces the image contrast and has a negative effect on texture based analysis. Moreover, as speckle noise changes the spatial statistics of the images, it makes the classification process a difficult task to do. Generally speaking there are two techniques of removing/reducing speckle noise, i.e., multi-look process and spatial filtering. Multi-look process is used at the data acquisition stage while spatial filtering is used after the data is stored. No matter which method is used to reduce/remove the speckle noise, they should preserve radiometric information, edge information and last but not least, spatial resolution. These are the conditions that any speckle noise reduction technique should meet. Spatial filters are mainly categorized into two general groups, i.e., non-adaptive and adaptive filters. Non-adaptive filters are those which neglect the local properties of the terrain backscatter or nature of sensor. However, adaptive filters accommodate the change in the local properties of the terrain backscatter or the nature of sensor. This paper reviewed the effect of applying six different adaptive filters on a simulated image as well as a real SAR imagery. To test the effect and performance of the filters, as the original and noisy image were available for the simulated image in Figure 1,2,3,4,5. One can use Mean Square Error, Signal to Noise ratio and β parameter (which shows the edge preserving strength of the filters). These three measures are able to evaluate the performance of filters quantitatively when both the original as well as noisy images are available. A good filter shows lower Mean Square Error, higher Signal to Noise Ratio, and a β closer to one. In both simulated and real imageries it is seen that regardless of the kernel size, Mean, Median and Local Region filters perform poorly. This sounds a reasonable result as these filters do not take all the statistical characteristics of the image into consideration. In case of simulated imagery it is seen that the Gamma-MAP filter with a 3x3 kernel has the lowest MSE and highest SNR and β in compare to other filters with the same kernel. However, Frost filter with a 7x7 kernel has the lowest MSE and highest SNR. The numerical results show that Gamma-MAP filter performs much better for preserving the edge information. In the case of real SAR imagery, the Gamma-MAP, Frost, and Lee filters with a 5x5 kernel show better results as the differences of their Means from the Mean of original image is low while they all have low Standard Deviation. SRAD is concluded as best among all the filters.

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