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Gradient based Adaptive Median filter for removal of Speckle noise in Airborne Synthetic Aperture Radar Images

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Abstract. Reduction of speckle noise is one of the most important processes to increase the quality of Synthetic Aperture Radar (SAR) coherent images. Image variances or speckle is a granular noise that inherently exists in and degrades the quality of the SAR images. Filtering is one of the common methods which are used to reduce the speckle noises. In this paper, gradient based adaptive median filter is proposed for removal of speckle noises in SAR images. Fourth order gradient is used to damper the high frequency components (speckle noises) in the SAR images. Effects of the curvature due to the gradient of the speckle noise are also avoided by the adaptive median filter in the proposed algorithm while reducing the speckle noises. This paper compares different speckle reduction filters quantitatively and qualitatively by applying on different SAR images. The results have been presented by filtered images, statistical tables and graphs.

Keywords: SAR images, Speckle noise, Gradient, Adaptive median filter, Mean Square Error (MSE).

1. Introduction

Synthetic aperture radar (SAR) is an active microwave sensor that transmits in microwave and detects the wave that is reflected back by the objects. SAR is completely different from passive optical sensors. It enables high-resolution, high contrast observation and accurate determination of topographical features when captured from an airplane or satellite as it makes use of radar waves to gather data about the earth below. SAR systems take the advantage of the long-range propagation characteristics of radar signals and the complex information processing capability of modern digital electronics to provide the high-resolution imagery. If the radar is attached to a moving platform on either an aircraft or a satellite, it is possible to combine reflected signals along the flight path to synthesize a very long antenna. In synthetic aperture radar (SAR) imaging as shown in fig 1, microwave pulses are transmitted by such antenna towards the earth surface. The microwave energy of the backscattered signal reflected back to the antenna is measured. Using the principle of radar, measuring the time delay of the backscattered signals enable formation of the image.

In real synthetic aperture radar imaging [1], an aircraft traveling forward in the flight direction with the nadir directly beneath the platform transmits a microwave beam towards the ground at right angles to the direction of flight revealing a swath which is offset from nadir. Typically, the imaging system relies on or across-track dimension perpendicular to the flight direction to measure the range and range resolution from the antenna to the target. The time elapsed between the transmission of a pulse to receiving the echo determines the range or Line-of-Sight, distance. The range resolution of the target is governed by the width of the receiving pulse where the narrower pulses give finer resolution. Another important dimension that imaging system relies on is the azimuth or the along-track dimension parallel to the flight direction and perpendicular to range. The resolution in this direction depends greatly on the azimuth beam width, which is inversely related to antenna size. A smaller antenna tends to generate a larger beam width and the corresponding images will have poor azimuth resolution.

To obtain fine azimuth resolution, a physically large antenna is needed to focus the transmitted and received energy into a sharp beam. However, airborne imaging system can still collect data while flying this distance and process the data as if it comes from a physically long antenna; that is to synthesize an extended

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antenna. A narrow synthetic beam width results from the relatively long synthetic aperture, which gives finer resolution than is possible from a smaller physical antenna. Another approach to explain how SAR imaging achieves fine azimuth resolution is based on Doppler processing. Doppler frequency of the echoes from the ground determines a target's position along the flight path. The offset is positive if the target is in front of aircraft or negative if target is behind the aircraft. When the aircraft flies a distance (the synthetic aperture), the echoes will be transformed into a number of Doppler frequencies where each frequency of a target helps to determine its azimuth position.

1.1. Interpretation of Synthetic Aperture Radar Image

The brightness or darkness of a SAR image pixel is dependent on corresponding 'patch' on the earth's portion of the transmitted energy that is returned back to the radar. In contrast to most optical remote sensing and surveillance systems, where aerial photographs and satellite images must be captured during the day and generally at a time when the sun is in a favorable position, active system such as radar has the advantage of providing its own source of energy for target illumination. The radar signal interacts with ground surfaces through reflection, scattering, refraction or being absorbed. Pixels in the image represent the back-scattered radiation from an area in the imaged scene. Brighter areas are produce by stronger radar response and darker areas are from weaker radar responses [1]. The amount of the occurrence of backscattering depends greatly on factors such as wavelength of the radar used, orientation or polarization, incidence angle of the radar wave and nature of the surroundings.

The length of the wavelength determines the resolution and penetration depth. A surface is considered smooth or flat if the height variations are smaller than the radar wavelength. For smooth surfaces, little of the radar signal will be reflected back to the radar system. This causes the area in the image to appear darker or invisible. In contrast, a surface appears rough to a shorter wavelength and a significant portion of the energy will be backscattered to the radar such that the rough surface will appear brighter in tone on an image. Longer wavelength can penetrate deeper into the canopy of trees and create multiple backscattering between the soils, leaves, branches and trunks. The large backscattering will cause the vegetation to give a brighter signature in image. Shorter wavelength will just interact with the top of the canopy causing detailed features such as small hills that are cover by the canopy to be hidden.

Radar polarization can enhance the feature on the ground. The reflected radar signal is much stronger when it is in line with the polarization of the electric field from the transmitted antenna. The ground targets respond differently to the various combinations of polarized radar. The incidence angle refers to the angle between the incident radar beam and the direction perpendicular to the ground surface. Incidence angle can alter the appearance of the image and reduced the image distortion. Larger angles cause weaker signals and larger radar shadow but image is less susceptible to layover. When features such as wall of a building or hedges lie in the direction of the flight-path, the radar beam can have two or double bounces occurring once on the wall surface and another off from the ground. This is known as corner reflection and most of the energy is reflected directly back to antenna resulting in a very bright appearance of the object in the image.

1.2. The Speckle Phenomenon

SAR is a coherent imaging technology that records both the amplitude and the phase of the back-scattered radiation. Speckle is a common noise-like phenomenon in all coherent imaging systems [2][3]. Each resolution cell of the system contains many scatterers, the phases of the return signals from these scatterers are randomly distributed and speckle is caused by the resulting interference. The speckle noises will appear as bright or dark dots on the image and leads to a limitation on the accuracy of the measurements given that the brightness of a pixel is determined not only by properties of the scatterers in the resolution cell, but also by the phase relationships between the returns from those scatterers. Speckle noise is multiplicative in nature, thus traditional filtering will not remove it easily. Speckle noise prevents automatically target recognition (ATR) and texture analysis algorithm to perform efficiently and gives the image a grainy appearance. Hence, speckle filtering turns out to be a critical pre-processing step for detection or classification optimization.

2. Speckle Removing Filters

There are various speckle reduction filters[4][5][6][7][8] available to process SAR images. Some give better visual interpretations while others have good noise reduction or smoothing capabilities. The use of each filter depends on the specification for a particular application. In practice, the standard speckle filters such as Median, Statistical Lee, Kuan, Frost, speckle reducing Anisotropic Diffusion (SRAD) and Sticks filter are considered to be the best speckle removing algorithms in the radar community. All the filters present in the literature for removal of speckle noise is not possible to discuss in this paper. Few speckle filters for SAR images are analyzed and the results are compared with the proposed gradient based adaptive median filter.

2.1. Gradient based Adaptive Median filter

Non-linear fourth order PDEs is a comparatively new approach for effective image denoising. A number of fourth order PDEs have been proposed in recent years for image denoising. Although discrete implementation of these methods produces impressive results, very little is known about the mathematical properties of the equations themselves. Indeed there are good reasons to consider fourth order equations. First, fourth order linear diffusion dampens oscillations at high frequencies (i.e. noise) much faster than second order diffusion. Second, there is the possibility of having schemes that include effects of curvature (i.e. the second derivatives of the image) in the dynamics, thus creating a richer set of functional behaviors. In the proposed model we used the L2-curvature gradient flow method. The model is shown in equation (1).

$$\partial u / \partial t = -\nabla^2[c (|\nabla^2 u|) \nabla^2 u] \quad (1)$$

where $\nabla^2 u$ is the Laplacian of the image u. Since the Laplacian of an image at a pixel is zero if the image is planar in its neighborhood, the PDE attempt to remove noise and preserve edges by approximating an observed image with a piecewise planar image. The desirable diffusion coefficient c(·) should be such that diffuses more in smooth areas and less around less intensity transitions, so that small variations in image intensity such as noise and unwanted texture are smoothed and edges are preserved. Another objective for the selection of c(·) is to incur backward diffusion around intensity transitions so that edges are sharpened, and to assure forward diffusion in smooth areas for noise removal.
The discrete form of non-linear fourth order PDE described in (1) is as follows:

$$u_{i,j}^{n+1} = u_{i,j}^{n} - \Delta t \nabla^2 g_{i,j}^{n} \quad (2)$$

$$\nabla^2 g_{i,j}^{n} = (g_{i+1,j}^{n} + g_{i-1,j}^{n} + g_{i,j+1}^{n} + g_{i,j-1}^{n} - 4g_{i,j}^{n}) / h^2 \quad (3)$$

$$g_{i,j}^{n} = g(\nabla^2 u_{i,j}^{n}) \quad (4)$$

$$\nabla^2 u_{i,j}^{n} = (u_{i+1,j}^{n} + u_{i-1,j}^{n} + u_{i,j+1}^{n} + u_{i,j-1}^{n} - 4u_{i,j}^{n}) / h^2 \quad (5)$$

Δt is the time step size and h is the space grid size. When fourth order diffusion is applied to the images, the areas having small gradients are smoothed, and which having large gradients edges and noise if any) remain undiffused and the blocky effects can be avoided. The gradients generated by noise can be subsequently removed by an adaptive median filter [1] without affecting the image structure. However if the gradients are generated by edges, the adaptive median filter will not affect them. So as iteration continues, the nonlinear PDE removes the low level noise and subsequently the adaptive median filter removes the impulsive noise spikes. The proposed method preserves image structure much better than the other similar methods.

3. Results and Discussions:

To obtain the optimal result in removing the speckle in SAR images using gradient based adaptive median filter, numerous simulations were carried out to collect the statistical data and the denoised images. The results obtained from the simulation are used to provide a comparative study on the performance of gradient based adaptive median filter and investigate the advantages and disadvantages of these techniques over standard speckle filters like Median, Lee, Kuan, Frost, decision based algorithm, sigma filters, sticks, SRAD and progressive switching median filter. The image quality metrics used are Mean Square Error(MSE), Peak Signal to Noise ratio (PSNR), Average difference (AD), Normalized Cross Correlation (NK), Normalized Absolute Error (NAE), Structural content (SC) and Mean difference(MD). Table 1 is the comparison table of different speckle removing filters at noise variance 0.1. Figure 2, 3 and 4 are the different filters output for speckle removal at noise variance 0.1, 0.4, and 0.005. Figure 5 is the comparison graph of MSE and PSNR of different algorithms. These simulations is coded in Matlab 2008A and tested in HPxw 4600 workstation.

Table 1. Comparison table of different speckle removing filters at noise variance 0.1

Var=0.1	**AD**	**NK**	**SC**	**MD**	**NAE**
Bilateral	128.027	0.00387	0.00035	251	0.9962
DBA	0.4170	0.99556	0.91771	126	0.2720
Frost	0.00668	0.9928	0.98455	110	0.14095
Lee	0.287	0.98972	1.00367	153	0.10408
Sigma	12.828	0.88442	1.25357	112	0.14019
Sticks	0.125	0.9800	1.185	198	0.15639
Proposed	**2.3107**	**0.9702**	**1.0408**	**151**	**0.1150**

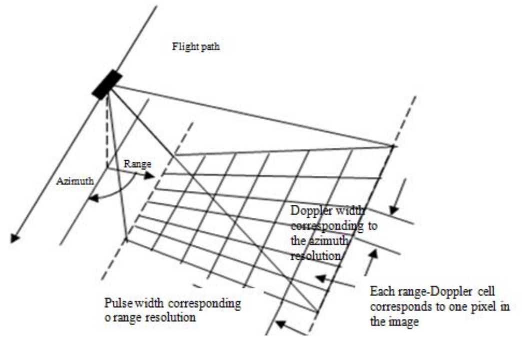

Fig 1. Principle of SAR Processing

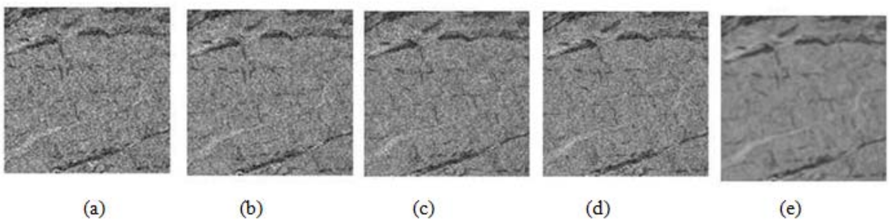

Fig 2. SAR image Denoising (a) noisy image of variance 0.1 (b) DBA filter output (c) Lee filter output (d) Sigma filter output (e) Proposed filter Output

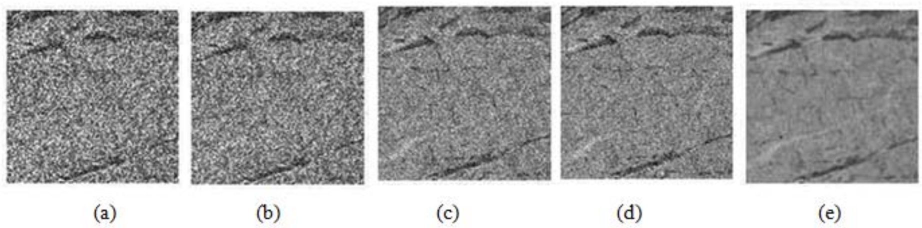

Fig 3. SAR image Denoising (a) noisy image of variance 0.4 (b) DBA filter output (c) Lee filter output (d) Sigma filter output (e) Proposed filter Output

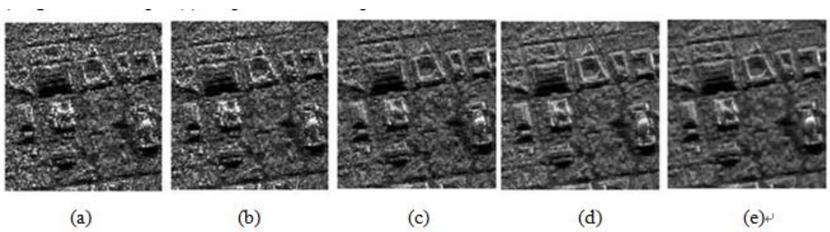

Fig 4. SAR image Denoising (a) noisy image of variance 0.05 (b) DBA filter output (c) Lee filter output (d) Sigma filter output (e) Proposed filter Output

4. Conclusion

SAR images 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, SAR images can provide us information from both surface and subsurface of the Earth. Inherent with SAR images is speckle noise which gives a grainy appearance to the images. 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. All of these show that to get information out of SAR images one should first remove/reduce the effect of speckle noise. A gradient based adaptive median filter is proposed for removal of speckle noises in SAR images. In this paper fourth order gradient is introduced to dampen the oscillations at high frequencies (i.e. noise) which are much effective than second order gradients. The proposed method reduce/remove the speckle noise, preserves information, edges and spatial resolution. And also the statistical measures of the proposed algorithm are comparatively better to the other existing algorithm.

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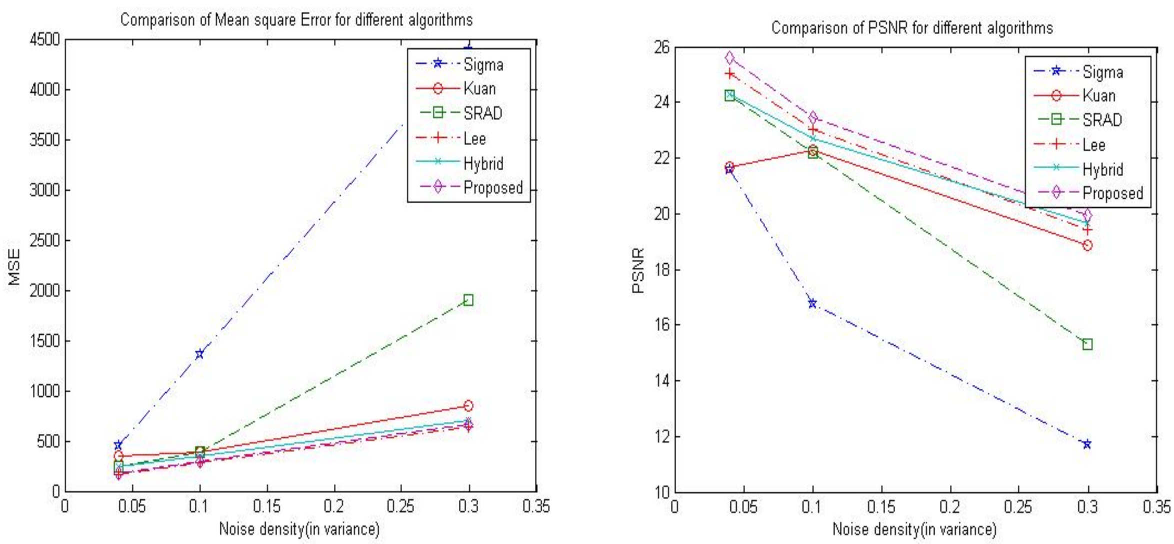

(a) (b)

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Fig 5. Comparison graph (a) MSE and (b) PSNR of different algorithms