Abstract

A new edge preserving wavelet filtering is proposed and it is applied to real SAR images that are generally affected by a multiplicative noise, called speckle, which degrades the quality of these images. The new approach attempts to look for the neighborhood area in the detail images of a wavelet decomposition, that identifies homogeneous areas and edge information by using masks in order to reduce speckle while edges are preserved. The improved filtering method uses the Nagao & Matsuyama and Tomita & Tsuji masks to detect edges locations in wavelet subspaces. The information provided by the masks is used to distinguish which of the detail coefficients are to be shrunk.

1. Introduction

Synthetic aperture radar (SAR) is an advanced microwave imagery system that provides high-resolution images independently of time and weather conditions [12]. SAR imagery is a kind of coherent system that produces a random pattern, named speckle, on the extended homogeneous areas of the image. In order to overcome this serious drawback in SAR images, it is essential to reduce speckle before procedures such as automatic target detection and recognition [7]. Recently, several filtering algorithms based on wavelet have been applied to SAR images attempting to reduce speckle. This approach provides a new powerful tool to localize frequency and spatial information about the signal and, in the field of remote sensing, wavelet based multiresolution analysis became a promising method. In [1] a new algorithm is proposed to achieve the goal of smoothing homogenous areas and sharpening edges. It acts as an adaptive-mean filter and edge crossing points are detected by using the second-order derivative of the Gaussian function as a wavelet transform function. A proper dilation scale factor enables the wavelet transform function to detect only edges crossing and ignore the local oscillations [1]. Olson [10] proposes a technique that convolves the noisy image with Gaussian derivatives at a discrete set of scales to perform filtering and detect features adaptively. In [7] an investigation is made about the remanent speckle noise in SAR images after filtering. It is well known that in case of image dependent noise, there is a compromise between noise reduction and edge preserving that leads to believe that some speckle remains in the filtered image.

In section II we present the new filtering approach to reduce speckle noise based on the wavelet decomposition of the original image using local information about edges information. Section III considers the experimental results and the measures to assess the filtering algorithms. Section IV summarizes the conclusions.

2. The Filtering Algorithms

The new filtering algorithms are based on the analysis of the detail images obtained from the wavelet decomposition of the original noisy image. The motivation of this work is the fact that in case of image dependent noise, it is a hard task to reduce noise efficiently without removing valuable information. The basic idea is to compute the wavelet decomposition of the noisy image and to reduce the amplitude of the insignificant detail coefficients in wavelet subspaces according to the edge masks information, while structural features are preserved.

One of the advantages of this approach over the traditional methods is the fact that the wavelet algorithm achieves the denoising in multiple scales although it is not based on the multiplicative model as the most popular filters including the Lee [6], Kuan [5] and Frost [2] filters.

2.1. Algorithm I

The operation of algorithm I follows the Fukuda & Hirosawa [3] algorithm but uses the combination of the
Nagao & Matsuyama [8] and Tomita & Tsuji [11] masks to select the detail coefficients to be preserved or to be thresholded in the neighborhood. In Figure 1 the used masks are shown. As in the Fukuda & Hirosawa work [3] the smoothing effect of our proposed speckle filter depends on the wavelet subspaces level and on the degree of the amplitude of the wavelet coefficients. These parameters have to be set according to the user’s desired smoothing effect [4]. In Figure 1 the neighborhood masks used in the filtering algorithm in place of the Fukuda’s masks are shown.

Although being similar, the neighborhoods in Figure 1 and Figure 2 affect the filtering algorithm in a slightly different way that can be noted in the evaluating measures.

2.2. Algorithm II

The operation of algorithm II follows the Fukuda & Hirosawa [3] filtering algorithm but uses an adaptive windowing scheme proposed by Park et al. [9]. In [9] an adaptive windowing algorithm was proposed to reduce speckle where the window size is automatically adjusted depending on the local statistics such as mean and standard deviation. The referred adaptive windowing algorithm is based on a measure of homogeneity ($\sigma_c$) estimated in the current window, in terms of the standard deviation to mean ratio. Among the elements in the current window $w_{ij}$, only the samples in the boundary of this window are used for the decision of the next window size to save the computational load [9]. The decision is done by comparing this estimated value with a standard one ($C$). The standard value ($C$) is adjusted to test images according to parameters such as the number of looks and the type of detection (linear or quadratic). The scheme proposed by Park et al. [9] suggested that if the running window met fine details such as edges and point targets the window size must be decreased down to the minimum window size (3x3 pixels). It means that if the calculated standard deviation to mean ratio value was above $C$ the class of terrain reflectivity corresponded to a heterogeneous one and must be preserved. If it was below $C$ it denoted an homogenous area and the next window size must be increased unless it was greater than the maximum value [9]. This described scheme was also studied and it was combined with the wavelet filtering in this paper and entitled algorithm II. As the noise is spread out over the details coefficients this new approach consists in running an adaptive window in the detail images looking for local statistically homogeneous area near the pixel. In case of amplitude detection and single look image the $C$ value is suggested to be the standard deviation of the speckle noise, $\sigma_n$. For linear detected and single look images this value is established to be 0.5227. In our proposed neighborhood scheme we start from the maximum window size that is 7 by 7 pixels and test its homogeneity threshold using only the pixels in the boundary. This group of pixels is shown in the dashed areas in Figure 3. In case that the calculated threshold is below the $C$ value the window size stops growing and the wavelet filtering algorithm proposed in [3] is applied, otherwise the window size must be decreased down to the minimum window size (3x3 pixels) in order to preserve edge and fine details.

3. Experimental Results

The original image in Figure 4a is a piece of a 512x512 pixels image of the National Forest of Tapajós, Pará, Brazil, taken on June, 26, 1993 by the JERS-1 satellite. It is a three looks, amplitude detected image. Figure 4b shows its histogram. The image in Figure 4c is a filtered version that was processed upon the algorithm I and Figure 4d is its histogram. Figure 4e is the filtered version obtained by applying the algorithm II and Figure 4f shows its histogram.
The original image in Figure 5a is a piece of a 512x512 pixels SAR image of a desert area (Kirtland Crater, New Mexico) obtained from the Airbone Multisensor Pod System. It is a single look and amplitude detected image. For the sake of improving the printing quality the brightness and contrast of the image were adjusted. Figure 5b shows its histogram. The image in Figure 5c is a filtered version that was processed upon the algorithm I and Figure 5d is its histogram. Figure 5e is the filtered version obtained by applying the algorithm II and Figure 5f is its histogram.
Another aspect to evaluate the speckle reduction algorithms is the histogram of the detail coefficients before and after thresholding them. The theory of wavelet denoising is based on the fact that the most significant detail coefficients contain the main characteristics of the signal, so it is possible to eliminate the least significant ones. Depending on the shrinkage function it is possible to reduce noise while preserving relevant features of the original image.

The detail coefficient values of the original Crater image before shrinking them are shown in the histogram of the Figure 6. A good shrinkage function should not
cause any discontinuity in the histogram of the filtered detail coefficients as shows Figure 7.

Figure 7. Histogram of the Crater image detail coefficients filtered by the Fukuda’s shrinkage function.

4. Conclusions

The qualitative performance of the proposed wavelet filters is visually satisfactory. Measures evaluating both the signal-to-noise improvement and radiometric distortion due to the filtering are computed. The calculated SNR to the algorithms I (Figure 4c) and II (Figure 4e) were 0.1949 and 0.1926, respectively. The theoretical mean value and standard deviation of the speckle fluctuations for single look and amplitude detected image are expected to be about 1 and 0.5227, respectively. The theoretical mean value and standard deviation of the speckle fluctuations for square root of gamma model (JERS image) are expected to be 1 and 0.2941, respectively [7]. If the reconstruction follows the original image too closely, the standard deviation of the pure speckle would be expected to have a lower value than predicted and the mean value should not depart significantly from the unitary mean. In Figure 4c the mean value and standard deviation of the pure speckle are respectively, 0.9733 and 0.1688. Applying the algorithm II (Figure 4e) these values were 0.9740 and 0.1688, respectively.

The Crater image processed by the algorithms I and II presented similar values with respect to the mean and standard deviation values of pure of speckle that are 0.9920 and 0.2987, respectively.

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6. References


