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Undecimated double density wavelet transform based speckle reduction in SAR images

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ABSTRACT

This paper describes an efficient and adaptive method of threshold estimation for removing Speckle noise from Synthetic Aperture Radar (SAR) images, based on Undecimated Double Density Wavelet Transform (UDDWT). Here the performance of image denoising algorithm is well improved by fixing different optimum threshold values for each wavelet coefficient. The choice of the estimation of the threshold value is carried out by analyzing the statistical parameters of the wavelet subband coefficients like Arithmetic Mean, Geometric Mean and Standard Deviation. Here the image is first decomposed into many subbands using UDDWT. Then based upon the statistical parameters of the wavelet coefficients of subbands, threshold values are found out for each wavelet coefficients. This threshold value is used in Soft Thresholding Technique to remove the noisy wavelet coefficients. Then the inverse transform is applied to get the denoised image. Evaluation parameters like peak signal to noise ratio, standard deviation to mean ratio and Edge Preservation Factor have been used for evaluating the performance of the proposed technique quantitatively. Experimental results on several benchmark images by using the proposed method show that, the proposed method yields significantly superior image quality. Some comparisons with the best available results will be given in order to illustrate the effectiveness of the proposed algorithm.

1. Introduction

Image denoising technique yields an improved estimate of an image corrupted by noise. The objective of noise removal is to suppress the noise while preserving the integrity of edge and detail information. Conventional denoising techniques like median [1], average [2] and ordered statistics filters [3] have demonstrated good proficiency in removal of Speckle noise. However, since these filters are typically implemented uniformly across an image, they also tend to modify pixels that are undisturbed by noise. The removal of noise by using such methods is often at the expense of blurred edge details and distorted features of image.

The denoising of SAR images corrupted by Speckle noise is a classic problem in Radar imaging. A good and effective denoising technique should not result in smoothing the edges of original image, but in image analysis, the removal of noise without blurring the image edges is a difficult task. Typically noise is characterized by high spatial frequencies in an image,

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Fourier-based methods usually try to suppress high frequency components, which also tend to reduce the sharpness of the edges. The wavelet transform is an important tool for this problem due to its energy compaction property. Moreover since the wavelet transform provides good localization in both spatial and spectral domains, low-pass filtering is inherent to this transform. Wavelet transform attempts to remove noise present in the image while preserving the signal characteristics regardless of its frequency contents. Many wavelet based techniques like hard and soft thresholding [4] were developed for removing random noise. In these techniques performance of denoising is totally depending upon the choice of threshold value. Researchers have developed various techniques for choosing threshold value like SUREShrink [5], VisuShrink [6] and Bayes Shrink [7]. Here we described adaptive and optimal threshold estimation technique for soft thresholding function for removing Speckle noise using Undecimated Double Density Wavelet Transform.

This paper is organized as follows: The characteristics of SAR image and Speckle noise is explained in Section 2. Section 3 deals with a brief review of Undecimated Double Density Wavelet Transform. The concept of proposed threshold value estimation technique and the various steps involved in the proposed denoising technique are explained in Section 4. In Section 5 the experimental results of this proposed work and other denoising technique are present and compared. Finally concluding remarks are given in Section 6.

2. SAR images and Speckle noise

SAR is a coherent imaging technology that records both the amplitude and the phase of the back-scattered radiation. Speckle [8,9] is a common noise-like phenomenon in all coherent imaging systems. 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 [10] 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 Automatic Target Recognition (ATR) and texture analysis algorithm to perform efficiently and gives the image a grainy appearance.

Theoretically the Speckle noise can be modeled by the relation

$$J = X + n \cdot X \tag{1}$$

where n is the uniformly distributed random noise with mean 0 and variance v, X the original image matrix and J the Speckle noise image.

3. Undecimated double density wavelet transform

Although the Discrete Wavelet Transform (DWT) [11–13] is a powerful signal-processing tool, it has two serious disadvantages:

1. Lack of shift invariance, which means that small shifts in the input signal, can cause major variations in the distribution of energy between wavelet transform coefficients at different scales.
2. Since the wavelet filters are separable and real, it causes poor directional selectivity for diagonal features.

The DWT is shift variant because, the transform coefficients behave unpredictably under shifts of input signal, a problem that has been treated by introducing large amounts of redundancy into the transform to make it shift invariant. The DWT has poor directional selectivity because it can only differentiate three different spatial-feature orientations. The Double Density Wavelet Transform (DDWT) is almost shift invariant, multi-scale transform and has eight different spatial-feature orientations. Because the DDWT, at each scale, has twice as many wavelets as the DWT, it achieves lower shift sensitivity than the DWT.

The Undecimated Double Density Wavelet Transform follows the same filter bank structures of DDWT except the up sampling/down sampling process. Here at any given level in the iterated filter bank, this separable extension produces nine subbands in the same size as the original image. To indicate the filters used along the row and column dimensions to create the nine subbands, the label of each of the sub-band is termed as h_y^i, h_x^j, $i,j \in \{0, 1, 2\}$. The subscript x indicates filtering along the rows, while subscript y denotes filtering along the columns. The superscripts 0, 1, 2 indicate the particular filter $h_0(n)$, $h_1(n)$, $h_2(n)$ used to filter along a specified dimension to create the subbands. Thus, at the end of the analysis filter bank, nine subbands will be obtained as shown in Fig. 1. In the UDDWT synthesis filter bank, the decomposed images are filtered using the filter coefficients $g_0(n)$, $g_1(n)$, $g_2(n)$. Fig. 2 depicts the synthesis filter bank structure, which composes the nine subbands into single image. In this work, the filters designed by Selesnick [14] are used for image decomposition and reconstruction, which are tabulated in Tables 1 and 2.

4. Proposed denoising algorithm

The wavelet transform yields a large number of small coefficients and small number of large coefficients. The small coefficients in the subbands are dominated by noise, while coefficients with large absolute value carry more signal information