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A new method for speckle reduction in Synthetic Aperture Radar (SAR) images using optimal window size

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Abstract. Speckle degrades the radiometric quality of a Synthetic Aperture Radar (SAR) image and makes its visual interpretation difficult. The approaches proposed previously for speckle filtering of SAR images exploit a window of fixed size for this purpose. But a fixed size window is not sufficient as the size of objects may vary throughout the image. In this paper, a method is introduced by which each pixel in the image is filtered using a window size which is optimal for that pixel. Real and imaginary parts of a single-channel SAR image are used for the selection of the best window size for each pixel, and then intensity image is filtered by applying that window size. The Average and Minimum Mean Square Error (MMSE) filters are modified using the Adaptive Window Size method. This approach is implemented on the HH-channel of a RADARSAT-2 image acquired over the Avalon Peninsula near St. John's, Newfoundland, Canada. This filter can supress speckle effectively while retaining the details reasonably.

1. Introduction

Speckle is a natural characteristic of Synthetic Aperture Radar (SAR) images. Speckle degrades the radiometric quality of the image and makes its visual interpretation more challenging. There is extensive literature on speckle reduction in SAR images. Lee was pioneering in this field by proposing the idea of adaptive filters; he developed a filter based on the idea of the Minimum Mean Square Error (MMSE) [1, 2]. This filter, however, failed to reduce speckle effectively near the edges [3] and thus a refined version of it [4] was proposed later. Lee proposed the sigma filter [5, 6] as well. Other researchers also suggested speckle filtering algorithms. For example, Frost [7, 8] solved the MMSE problem with a different error measure. Kuan [9] developed a filtering function similar to Lee's, but some parameters were different. A comprehensive review of filters is provided in [10-12].

Although the above-mentioned filters perform well in SAR images, it is a challenge to select window size for these filters. In fact, choosing a fixed size window for filtering SAR images is not effective enough, because different objects in the image are not of similar size. Thus, filtering with a window of fixed size either blurs the image in heterogeneous parts or leaves speckle in homogeneous parts. This paper introduces a method for filtering each pixel with its own adaptive window. Details are presented in the following sections.

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2. Method

The best filtering window for each pixel is the one that contains maximum pixels from the same target as the central pixel, and minimum pixels from the other targets. Let us consider each pixel as an independent observation for estimating the backscatter coefficient of the whole target in which the pixel lies. Assume that the independent observations made for a target are in real and imaginary format. Considering that the mean is an efficient estimator for normally distributed data [13] and real and imaginary data tend to have normal distribution [3], it can be concluded that, as the filtering window for averaging the pixels grows larger, the standard deviation will tend to decrease until it contains outliers, i.e., any observation from other targets. With this explanation, the best window size for filtering each pixel is the one that corresponds to the minimum standard deviation in filtering real and imaginary images. If the window size obtained from real and imaginary data is different, their average is considered. Then, it is the intensity image that is filtered using the optimal window size for each pixel, because filtering real and imaginary data does not have any effect on speckle reduction. Filtering each pixel with an adaptive window size is expected to retain fine features, edges and lines, because each window contains observation from one target only.

Based on the explanation above, the following procedure should be adopted for filtering with adaptive window size. First, each pixel in both real and imaginary images is averaged with a range of window sizes, and corresponding standard deviations are also computed. Then, for each pixel the window corresponding to the minimum standard deviation is selected as the optimal one, and the intensity image is filtered using that. Filtering of the intensity image can be performed using different methods; it can be a simple averaging, or the modified MMSE filter as will be elaborated below.

2.1. MMSE filter with adaptive window size

MMSE filter [1] has the following form:

$$\hat{R}(x,y) = W(x,y) * I(x,y) + \left(1 - W(x,y)\right) * \bar{I}(x,y)) \tag{1}$$

In equation (1), $\hat{R}(x,y)$ is the estimated intensity of the pixel (x,y), $I(x,y)$ is the observed intensity for the pixel (x,y) and $\bar{I}(x,y)$ is the average intensity in a local window. $W(x,y)$ is a weight parameter which is computed by the following formula:

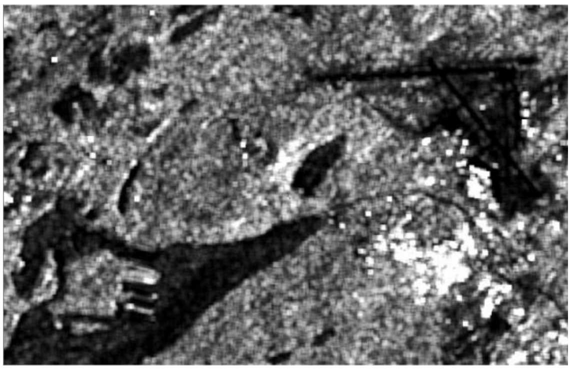
$$W(x,y) = \frac{\sigma_R^2(x,y)}{\sigma_I^2(x,y)} \tag{2}$$

where $\boldsymbol{\sigma_I^2}$ is the variance of the intensity in the local window and $\boldsymbol{\sigma_R^2} = \frac{\sigma_I^2 - \bar{I}^2\,\sigma_u^2}{(1+\sigma_u^2)}$. $\boldsymbol{\sigma_u^2}$ is a characteristic of speckle which is the ratio of the standard deviation to the mean in a homogeneous area and its value for single-look SAR data is 1 [14]. For modifying the MMSE filter to be applied with an adaptive window size, it is enough to replace $\boldsymbol{\bar{I}(x,y)}$ in equation (1) and $\boldsymbol{\sigma_I^2(x,y)}$ in equation (2) with the mean and standard deviation of intensity values in the optimal window pixel $(\boldsymbol{x},\boldsymbol{y})$, respectively.

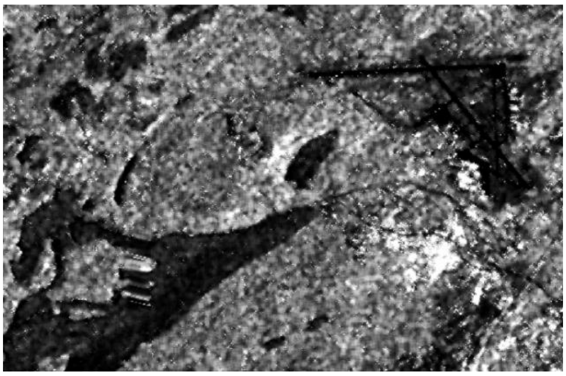
3. Results and discussion

For implementing the method, a 7 km by 5 km sub-image was selected from a fully polarimetric RADARSAT-2 image taken over the Avalon Peninsula near St. John's, Newfoundland, Canada. The image was acquired in FQ4 beam mode on July 10, 2015 in Single Look Complex (SLC) format. The results were implemented on the HH channel of the image and are illustrated in Figure 1.

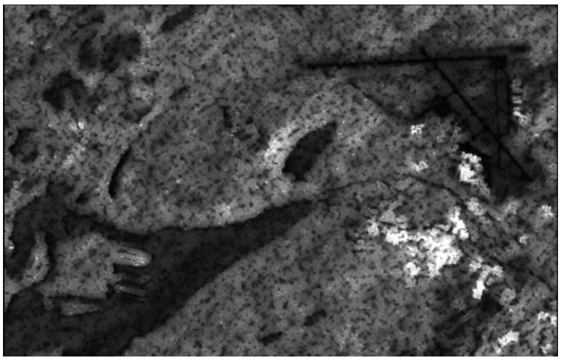
(A)



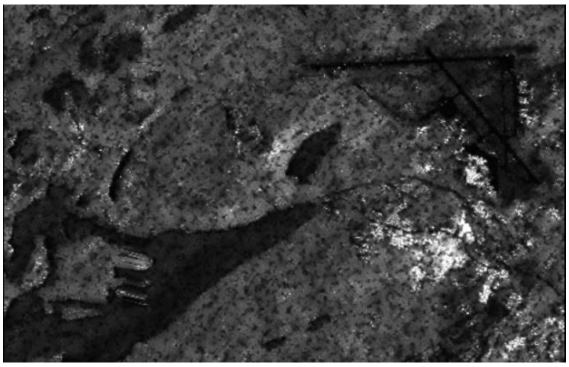
(B)



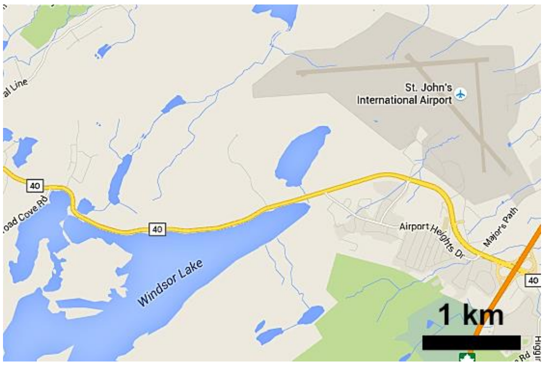
(C)



(D)



(D)



(E)

Figure 1. (A) Original one-look HH intensity image; (B) 5×5 average filtered image; (C) 5×5 MMSE filtered image; (D) average filtered image with adaptive window size; (E) MMSE filtered image with adaptive window size; and (F) map of the study area map (adapted from Google Maps™)

The original image is clearly affected by speckle. The average filter has supressed speckle effectively, but it has also blurred the details. The Lee filter has retained more subtle features. A fair amount of speckle, however, is still present in the image and occasional points with higher intensity can be seen in the image. The Average Filter with adaptive window size has performed better, as it retains image detail and performs speckle suppression effectively, with slight over-filtering of some parts. This downside cannot be seen in the image filtered using MMSE with adaptive window size.

For a more detailed comparison, the Equivalent Number of Looks (ENL) is also computed for different images. For intensity images, ENL [3] is defined in equation (3), as follows:

$$ENL = \frac{(mean)^2}{variance} \quad (3)$$

A large value for ENL shows an effective suppression of speckle. The values of ENL for different images illustrated in Figure 1 are listed in Table 1; both Average Filter with adaptive window size and MMSE Filter with adaptive window size have a higher ENL value relative to other types of filters. The box-car filter is the only kind that has a higher ENL than the proposed filters. However, as discussed before, it blurs the details of the image and thus is not the ideal filter to use.

Table 1. Equivalent Number of Looks (ENL) for different types of images

Image	ENL
Original Image	0.8919
Average Filter	10.4493
MMSE Filter	7.0836
Average Filter with adaptive window Size	10.2089
MMSE Filter with adaptive window size	9.3788

4. Conclusion

This paper presents a method for filtering SAR images using filters of adaptive size. Real and imaginary images are used for selecting an appropriate window size for each pixel. Then intensity image is filtered using the selected window. Average and MMSE filters have been modified and presented with adaptive window size. The proposed filters outperformed their traditional counterparts and were able to suppress speckle effectively while retaining image detail.

5. References

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