The Improvement of PolSAR Speckle Reduction Based on MMSE

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Abstract. Speckle reduction plays an important role in the understanding of SAR images. An improved method is proposed in this paper aiming at solving the complex problem of speckle reduction based on the pre-classification. In this method the Wishart classification is replaced by a simple one, which is based on span and Freeman decomposition. As a result, the complexity is reduced. At the same time, a satisfied result is obtained. The application to AIRSAR data shows that the new method is effective to PolSAR speckle reduction.

Keywords: PolSAR • Speckle reduction • MMSE • Scattering model

1 Introduction

Synthetic Aperture Radar (SAR) image suffered from speckle because of the coherent imaging, which lowers image quality and produces serious influence on the applications of SAR images, such as segmentation, edge extraction and target detection. Therefore, speckle reduction is one of the important preprocessing steps in SAR image understanding.

Polarimetric Synthetic Aperture Radar, PolSAR, can provide richer information and is becoming one of the important trends of SAR technology. In 1990, Novak and Burl proposed the Speckle Reduction method of PWF to PolSAR images[1]. This method reduces the standard deviation-to-mean ratio 4.8 dB relative to that of a single-channel. But it lost the polarimetric information. In 1991, reference [2] provided Lee refined filter based on multiplicative noise model and minimizing the mean-square error (MMSE), but it is not effective to off-diagonal terms. Lopes and Goze expanded the refined filter to all elements of the one-look covariance

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matrix[3]. In 1999, Lee introduced eight edge-aligned window into MMSE filter to preserve the structure and edge in SAR images[4].

So far, the MMSE filter has been widely used in polarimetric SAR speckle reduction. Based on different method of pixels choosing in parameter estimation, there are different filters can be used, such as boxcar method, prewitt method[4], pre-classification method[5] and so on. In 2006, Lee provided the speckle reduction method using pre-classification based on scattering models[6]. This method is effective but it needs a lot of calculation, especially the Wishart iterative classification. Some of the recent proposed methods are based on the idea of pre-classification.

In this paper, the MMSE method is studied using different parameter estimation method. Aiming at reducing the complexity of speckle reduction based on the pre-classification, an improvement is developed. The Wishart classification is replaced by a simple one based on span and Freeman decomposition in this new method.

2. The polarimetric speckle reduction based on MMSE

2.1 The MMSE speckle reduction of polarimetric SAR image

Based on multiplicative noise model, the observed quantity is

$$z = vx \tag{1}$$

Where v is multiplicative noise. Its mean value and variance are 1 and σ_v^2, respectively. x is truth-value.

It is assumed that x and v are statistically independent. $\hat{x}$ and $\bar{x}$ are the estimated and the mean of x, respectively. Then

$$\hat{x} = a\bar{x} + bz \tag{2}$$

Where $a + b = 1$. According to the MMSE criterion in literature [7], there is

$$\hat{x} = \bar{z} + b(z - \bar{z}) \tag{3}$$

Where $\bar{z} = E[z] = \bar{x}$, $b = \dfrac{\text{var}(x)}{\text{var}(z)}$.

Equation (3) is the filtering formula in the condition of multiplicative noise. Lee has applied the speckle reduction method based on MMSE to multi-polarized SAR images. The vector is filtered by the local statistical method. Suppose that,

$$X = \begin{bmatrix} x_{hh} & x_{hv} & x_{vv} \end{bmatrix}^T \tag{4}$$

We derive,

$$Z = VX \tag{5}$$

Where V is the multiplicative noise. Its mean value and variance are I and σ_v^2, respectively.

According to the MMSE criterion, the estimate $\hat{X}$ of X is expressed as (6).

$$\hat{X} = \bar{X} + MP^{-1}(Z - \bar{X}) \tag{6}$$

Then we get (7).

$$M = \left(P - \bar{Z}^2 \sigma_v^2\right) \big/ \left(1 + \sigma_v^2\right)$$
$$P = Cov(Z) \tag{7}$$

Where $\bar{X}$ is the priori mean of each pixel. $\bar{Z}$ is the mean of the test vector, so that we have $\bar{X} = \bar{Z}$.

The aforementioned speckle reduction is based on vector filtering. Lee and his co-workers improved the parametric estimation in the MMSE speckle reduction and finally gave the method based on polarimetric covariance matrix shown as (8).

$$\hat{C} = \langle C \rangle + b(C - \langle C \rangle) \tag{8}$$

Where $\hat{C}$ is the covariance matrix after speckle reduction, whose mean value is $\langle C \rangle$. Lee used total span to evaluate b. The span value is calculated by different polarized channels instead of single channel since multiplicative noise is less. In addition, the total span can show nearly all the features of polarimetric images. Therefore, the use of total span to detect edge is more typical.

2.2 The MMSE speckle reduction based on pre-classification

As is shown in equation (7), polarimetric speckle reduction based on the MMSE criterion needs to evaluate $\langle C \rangle$ and b. The simplest way is to evaluate with sliding window. In 1999, Lee et al used Prewitt edge operator to evaluate speckle reduction parameters[4] in order to preserve texture details better. In 2003, Yoon proposed classified pixel-based fitering idea [5] for polarimetric SAR image, which segment homogenous region and evaluate parameters according to the results of classification. Though we classify the whole pixels into 8 classes, we just use one main class to evaluate parameters when implementing this method. If there is large difference between target pixels and the main class in scattering characters, the speckle reduction parameters will be inaccurate. Meanwhile, the me-

thod is not sensitive to point targets because it will scatter the point targets. In 2006, Lee et al [6] have proposed a pre-classification method of homogenous regions based on scattering model, which can be applied to the scene with complicated textures.

2.3 Examples of the MMSE speckle reduction

In order to evaluate the performance of speckle reduction based on the MMSE method, the L-band data provided by the NASA/JPL AIRSAR can be used in our experiment, which was collected in San Francisco. The original MMSE speckle reduction method used the whole covariance matrix. While in this paper, we just show the result of HH channel. The original image of HH channel is shown in Fig.2.1.(a). Fig.2.1.(b),(c) and (d) represent the results of speckle reduction with boxcar, Prewitt window and scattering model pre-classification, respectively.
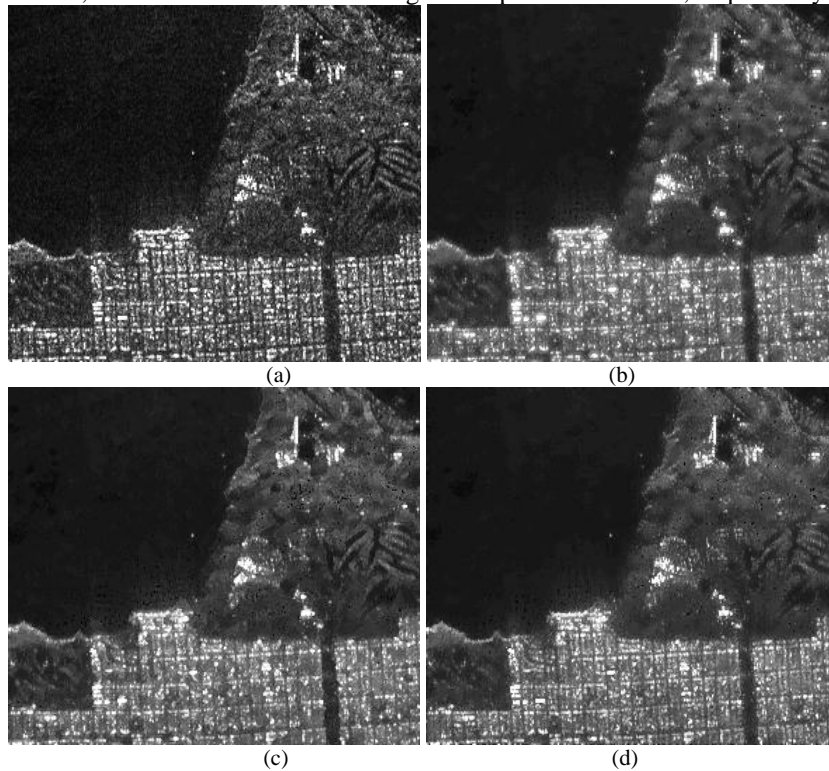

(a)   (b)

(c)   (d)

Fig.2.1. HH channel image comparison before and after speckle reduction

From Fig.2.1 we can see that the speckle has been obviously weakened. After the processing of rectangular window, the edge of image is the bleariest and the

spreading of point target is the most serious. In order to compare the spread of the point target, we take Fig.2.2 as an example. As is shown by yellow arrows, a bold line has been marked for the sake of observing. The values of the marked line before and after speckle reduction are shown in Fig.2.2(b), and we can know that the method based on scattering model pre-classification have the best preserving effect while the result of the boxcar window is the worst.
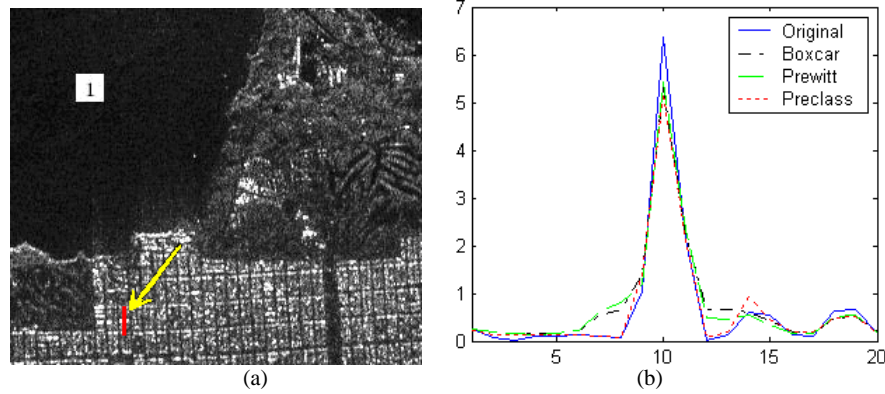

(a)   (b)

Fig.2.2 the statistical region of speckle reduction effect and the comparison of spread of point target in HH channel

In order to compare the results of different speckle reduction methods, we select region 1 as the statistical region and use the speckle factor, which is defined as deviation-to-mean ratio, to measure the effects. The smaller the speckle factor is, the better the effects of speckle control are.

The simulation result shows that the speckle factor value（s/m value） for original image is 0.6311, while for boxcar method, Prewitt method, Pre-classification method are 0.2450, 0.2848, 0.2039 respectively. Therefore, the method based on scattering model pre-classification can get the minimum value and is the most effective way to reduce speckle among them. We can also know that the scattering model pre-classification method can get good results both on preserving edge, point target and reducing speckle.

3 the improvement of scattering model pre-classification

The advantage of speckle reduction based on scattering model pre-classification is that the pixels, which are used to evaluate parameters, have the same or similar scattering mechanism and can be classified subtly. The application of the method can get a good speckle reduction effect. but the processing of the method includes Freeman decomposition, clustering, clusters merging and iterative classification, among which the most complex step is the iteration for the large computation. The

purpose of Freeman decomposition is to classify targets into three different scattering mechanisms. The pixels in each scattering mechanism will exhibit different scattering characteristic since the materials and properties of pixels are different. The method uses Wishart iterative classification to classify the pixels. If we use smaller computation and easier classification instead of the said subtly classification, the speckle reduction effect will decrease since the classification of the homogenous may be rough. We may find a balance between speckle reduction effect and computation if there is a possibility that we can reduce the computation a lot while the speckle reduction effect decreases a little.

The improved method firstly classifies pixels into three scattering mechanisms by Freeman decomposition. Pixels of the same kind can be divided into homogenous pixels and non-homogenous pixels according to span parameter. The speckle reduction parameters of MMSE can be evaluated by homogenous pixels. In actual implement, we firstly classify pixels into three scattering mechanisms by Freeman decomposition, and then find homogenous pixels with the center pixel in a rectangular region according to span parameter and scattering mechanism. Take window 7*7 as an example, pixels that fulfill the following requirement are homogenous pixels.

$$\begin{cases} D(i,j) = D(4,4) \\ \left| P_{i,j} - P_{4,4} \right| \le k\sigma \end{cases} \quad i,j = 1,2...7 \tag{9}$$

Where $D(i,j)$ is result of Freeman decomposition of the (i,j)th pixel. $P_{i,j}$ is span value of the (i,j)th pixel. i and j are the indexes of the pixel in window. σ is standard variance of pixels in the processing window. k is coefficient.

In order to evaluate the performance of the improved method, the PolSAR image of San Francisco has been used. We reduce speckle under different k, ranging from 1.5 to 4.5. We still use region 1 in Fig.2.2 (a) to calculate speckle factor, which are listed in Table3.1. As we can see from table 3.1, with the increase of k, speckle factor has the trend to decrease. The spread of the point target is shown in Fig.3.1. The point will spread seriously with the increase of k. When k range from 2.5 to 3.5, the s/m has the values from 0.2462 to 0.2538. Though it is higher than scattering model pre-classification, it is better than Prewitt method.

Table 3.1 speckle factor of speckle reduction based on simplified pre-classification

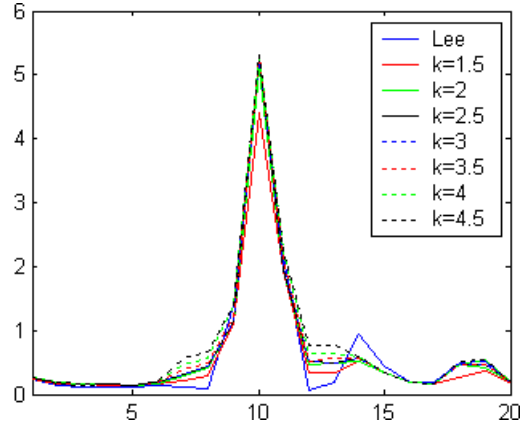| k	1.5	2	2.5	3	3.5	4	4.5
s/m	0.2959	0.2673	0.2538	0.2471	0.2462	0.2441	0.2443

Fig.3.1 The spread of point target

The results of speckle reduction with $k = 2.5$ and $k = 3.5$ are shown in Fig.3.2. The speckle is reduced effectively, and the texture, edge and the points are preserved well.

Compared with the speckle reduction based on iterative classification, the result of the improved method is worse, but it greatly simplifies the implementation process. The calculation time of the improved method is just about 15.3% of that of iterative classification under 4 iterations. Therefore, considering the complexity and speckle reduction effect, the improved method is also a valid way to reduce speckle in appropriate value of k.
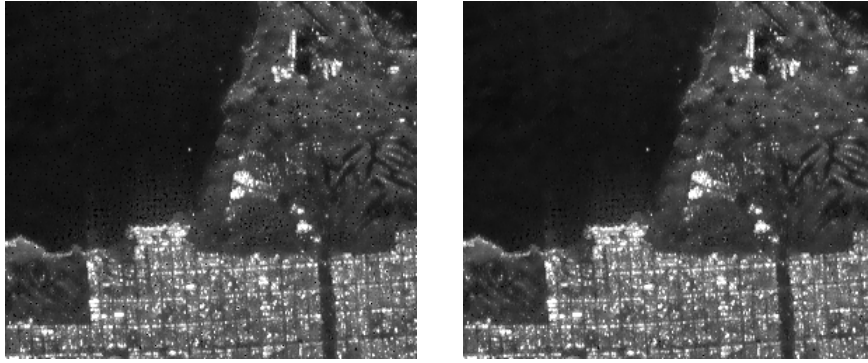

Fig. 3.2 Results of speckle reduction (left: k =2.5, right: k =3.5)

4 Conclusions

In this paper we studied the polarimetric speckle reduction based on MMSE, and we used measured data to prove the performance of speckle reduction based on scattering model pre-classification, the texture preserving and speckle reduction of which are better than Prewitt window method. Although the simple rectangular window method can reduce speckle well, the edge of texture region is blurred seriously.

The paper proposed an improved method based on Freeman decomposition and span parameters since the pre-classification method proposed by Lee is complex in implementation. The experimental results show that the improved method will significantly reduce implementation complexity and get a good speckle reduction effect. Though compared with the pre-classification proposed by Lee, the improved method has less effect in speckle reduction and texture preserving, it is still better than the widely used Prewitt method. And in computation aspect, the improved method has obvious improvement compared with Lee's method. Therefore, the new method finds a balance between implementation complexity and speckle reduction performance of Lee's method, so it is also a valid polarimetric SAR speckle reduction method.

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