IMPROVED MULTILOOK TECHNIQUE APPLIED TO SAR IMAGES

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ABSTRACT

The multilook technique used in synthetic aperture radar image formation consists in adding incoherently M looks. As these looks can be obtained in their complex form and are correlated, the phase and correlation informations should be taken into account in the speckle reduction process. In this paper, we propose an improved multilook technique based on the use of these two informations. We apply it on SAR images displaying ship wakes. Our technique consists in enhancing a specific texture in the image, using a set of filters matched to it, while simultaneously reducing speckle. The filters are applied on each look, and the resulting images are projected onto a particular basis. The final image is constituted by the quadratic sum of the processed looks, after their projection on the same geographic plane. Illustrative results as images comparison and analysis will show the effectiveness of the proposed algorithm.

1. INTRODUCTION

Recently, there has been a great deal of research dedicated to ship wake detection in synthetic aperture radar (SAR) images. Some of these detection algorithms use the Radon transform [1]-[2]. Another algorithm performs the detection on both ship and ship wakes [3].

Most of the detection algorithms first pre-filters the data in order to improve the visibility of ship wakes [2]. In this paper, our objective is to enhance SAR images of ship wakes, using an improved multilook technique.

In synthetic aperture radar image formation, a common approach for reducing speckle is constituted by the multilook technique. Several improved multilook techniques have been proposed in the literature [4]-[6]. In [4], the case of a moving point target is taken into account in the look summation. Another technique gives each look specific sizes and weights before summation, in order to improve the radiometric resolution [5].

The different looks can be obtained in their complex form. The idea of using the phase and correlation informations in the multilook technique has been explored in [6].

We also use the phase and correlation informations. Our technique consists in building filters matched to a particular texture caracterised by its covariance matrix. If we consider complex looks, the matrix will be composed of coefficients representing the correlation between the in-phase and quadrature components of each look, and the correlation between the different looks. If we consider the modulus of the complex looks (case of amplitude looks), the matrix will be composed of coefficients representing only the correlation between the different looks.

The covariance matrices of the texture and noise appear in the signal to noise ratio. The expression of the filters is derived by maximizing this ratio. We obtain several filters for each look (either in its complex or amplitude form). The resulting images are then projected onto a basis having specific properties.

Section 2 presents the mathematical formulation of the process. Its application to the multilook technique is described in section 3 for the cases of complex and amplitude looks. Experimental results are then presented in section 4.

2. MATHEMATICAL FORMULATION

The filters we use are called stochastic matched filters. They are issued of previous work and are described in [7]. A brief description is given here. The term stochastic is used here because several observations of the signal (or texture) and noise are considered.

2.1. Stochastic matched filters

• Let S be the signal vector corresponding to the texture to enhance and let N be the vector corresponding to the noise. Matched filter technique consists in finding a function H in order to maximize the signal to noise ratio K, expressed by the following relation

$$K = \frac{H^t E\{SS^t\}H}{H^t E\{NN^t\}H} \tag{1}$$

where $()^t$ represents the transposition.

 $E\{SS^t\}$ and $E\{NN^t\}$ are respectively the covariance matrices of the texture and noise. K can be written as:

$$K = \frac{\sigma_s^2}{\sigma_n^2} \frac{H^t \Gamma_0 H}{H^t R_0 H} \tag{2}$$

where Γ_0 and R_0 are respectively the normalized covariance matrices of the texture and noise. The calculation of the covariance matrices of the texture and noise are similar, so we will only show the procedure for the determination of Γ_0 in section 3. • K is a Rayleigh quotient, so it will be maximized if H is the eigenvector corresponding to the maximal eigenvalue of the matrix C expressed by

$$C = R_0^{-1} \Gamma_0. \tag{3}$$

Suppose that C has T distinct eigenvalues. The corresponding eigenvectors are $H_0, H_1, \ldots, H_{T-1}$, and we have:

$$\Gamma_0 H_i = \lambda_i R_0 H_i.$$

Taking

$$Y_i = R_0 H_i \tag{4}$$

we obtain $C^t Y_i = \lambda_i Y_i$ and Y_i constitute an eigenvector of C^t . So we have

$$H_i^t R_0 H_j = 0$$
 if $i \neq j$.

The eigenvectors H_i are normalized as follows:

$$H_i^t R_0 H_i = 1$$

So the eigenvectors correponding to eigenvalues greater than 1 can contribute to an improvement of the signal to noise ratio.

• Let P be the number of eigenvalues greater than 1. The decomposition of the signal S and the noise N on the basis constituted by the P vectors Y_i leads to the following expressions:

$$S = \sigma_s S_0 = \sigma_s \sum_{i=1}^P v_i Y_i, \qquad (5)$$

$$N = \sigma_n N_0 = \sigma_n \sum_{i=1}^{P} w_i Y_i.$$
(6)

where

$$v_i = H_i^t S_0; (7)$$

$$w_i = H_i^t N_0. (8)$$

 v_i and w_i are random variables having the following properties:

$$E\{|v_i|^2\} = \lambda_i, \quad E\{v_i v_j\} = 0;$$
(9)

$$E\{|w_i|^2\} = 1, \quad E\{w_iw_j\} = 0.$$
 (10)

Let I be the observed signal. We have

$$I = S \odot B$$

where S represents the signal, B the speckle noise with mean 1 and \odot the component wise product. I can be rewritten as [8]

$$I = S + N$$

where ${\cal N}$ is a signal-dependent noise. ${\cal I}$ is decomposed as

$$I = \sum_{i=1}^{P} (\sigma_s v_i + \sigma_n w_i) Y_i \tag{11}$$

The mean square value of the i^{th} component of I is expressed by

$$\mathbb{E}\{\sigma_s v_i + \sigma_n w_i)^2\} = \sigma_s^2 \lambda_i + \sigma_n^2 + 2H_i^t H_i \mathbb{E}\{SN^t\},\$$

so the signal to noise ratio for this component is

$$K = \frac{\sigma_s^2 \lambda_i}{\sigma_n^2 + 2H_i^t H_i E\{SN^t\}}.$$
 (12)

To take into account the effect of the term $2E\{SN^t\}$, we will use the eigenvectors corresponding to some greatest - but not all - eigenvalues. But given the preceding model, N can be written as

$$N = f(S)n$$

where f(S) represents the signal dependence and n the zero mean noise. As f(S) and n are independent, we have

$$E\{SN^t\} = E\{Sn^t f(S)^t\}$$
$$= E\{Sf(S)^t\}E\{n^t\}$$
$$= 0$$

So we can expect that the term $E\{SN^t\}$ is weak.

2.2. Multidimensional stochastic matched filters

The extension of the technique to the multidimensional case is given in [9]. We consider M signals, having respectively textures denoted S_1, S_2, \ldots, S_M , and noise N_1, N_2, \ldots, N_M . They can be decomposed as follows:

$$S_j = \sum_{i=1}^{P} v_i Y_{i,j};$$
 (13)

$$N_j = \sum_{i=1}^{P} w_i Y_{i,j}.$$
 (14)

with $j \in \{1 \dots M\}$ and where

$$v_{i} = H_{i,1}^{t}S_{1} + H_{i,2}^{t}S_{2} + \ldots + H_{i,M}^{t}S_{M};$$

$$w_{i} = H_{i,1}^{t}N_{1} + H_{i,2}^{t}N_{2} + \ldots + H_{i,M}^{t}N_{M}.$$

 $H_{i,j}$ is the eigenvector corresponding to the i^{th} eigenvalue and to the j^{th} signal. We have

$$Y_{i,j} = R_0 H_{i,j}.$$

Considering that the M signals are represented by M looks, it is possible to apply this decomposition to each look, before summing them to obtain the final image. As we have complex and amplitude looks, we will obtain different covariance matrices for the signal and the noise. For the complex case, the covariance matrix will take into account the phase and correlation informations. For the amplitude case, only the correlation between the looks will be used. The next section presents this improved multilook technique.

3. IMPROVED MULTILOOK TECHNIQUE

3.1. Case of complex looks

- On each complex look, several observations of the texture and noise are chosen. In our case, texture corresponds to ship wakes. The noise is chosen in homogeneous areas. Each observation is constituted by a (L, L) sub-image. Each sub-image is put under a vector form $(L^2, 1)$.
- Let $I_k(L^2, 1)$ and $Q_k(L^2, 1)$ be respectively the signal vectors representing the texture of the in-phase and quadrature channels of the k^{th} look. A signal vector $S(2 \times L^2 \times M, 1)$ is built by concatenating M vectors of the in-phase and quadrature channels (one vector for a look). So this signal vector S is expressed by

$$S = (I_1 \ Q_1 \ I_2 \ Q_2 \ \dots \ I_M \ Q_M)^t.$$

Let N be the vector corresponding to the noise. N is obtained in the same way as S. We have

$$\sigma_s^2 \Gamma_0 = E\{SS^t\}$$

so we obtain

$$\sigma_s^2 \Gamma_0 = \begin{bmatrix} \Gamma_{1,1} & \Gamma_{1,2} & \dots & \Gamma_{1,M} \\ \Gamma_{2,1} & \Gamma_{2,2} & \dots & \Gamma_{2,M} \\ \vdots & \vdots & \ddots & \vdots \\ \Gamma_{M,1} & \Gamma_{M,2} & \dots & \Gamma_{M,M} \end{bmatrix}$$
(15)

where $\Gamma_{k,l}$ is the covariance matrix of the texture belonging to complex looks k and l. This covariance matrix is composed of sub-matrices and can be written as

$$\Gamma_{k,l} = \begin{bmatrix} \Gamma_{I_k I_l} & \Gamma_{I_k Q_l} \\ \Gamma_{Q_l I_k} & \Gamma_{Q_k Q_l} \end{bmatrix}.$$
 (16)

So correlations between the in-phase and quadrature components of each look and correlations between the looks are represented here.

• Given the form of the signal and noise matrices, each eigenvector H_j has a length equal to $2 \times L^2 \times M$. So H_j is composed of sub-vectors having a length equal to L^2 , that's why we have one filter for each part of a complex look.

Only the eigenvectors H_j whose corresponding eigenvalues are sufficiently high are taken into account, so each complex look is filtered successively by the corresponding sub-vectors to obtain the random variables v_i and w_i . Note that in order to filter a look, each sub-vector $(L^2, 1)$ is put under a bidimensional form (L, L).

Then the filtered looks are projected onto the basis of the Y_i vectors. Finally, the resulting images are projected onto the same geographic plane and then summed incoherently.

3.2. Case of amplitude looks

Let $X_k = \sqrt{I_k^2 + Q_k^2}$ be the signal vector $(L^2, 1)$ representing the texture of the k^{th} look. A signal vector $S(L^2 \times M, 1)$ is built by concatenating M signal vectors corresponding to M looks. So this signal vector S is expressed by

$$S = (X_1 \ X_2 \ \dots \ X_M)^t.$$

N is obtained in the same way as S. The expression of the covariance matrix of the texture is given by

$$\sigma_s^2 \Gamma_0 = \begin{bmatrix} \Gamma_{X_1 X_1} & \Gamma_{X_1 X_2} & \dots & \Gamma_{X_1 X_M} \\ \Gamma_{X_2 X_1} & \Gamma_{X_2 X_2} & \dots & \Gamma_{X_2 X_M} \\ \vdots & \vdots & \ddots & \vdots \\ \Gamma_{X_M X_1} & \Gamma_{X_M X_2} & \dots & \Gamma_{X_M X_M} \end{bmatrix}$$
(17)

where $\Gamma_{X_k X_k}$ is the signal covariance matrix of the k^{th} look, and $\Gamma_{X_k X_l}$ represents the intercorrelations existing between signals of the k^{th} and l^{th} look.

4. EXPERIMENTAL RESULTS

Illustrative results are presented in this section for an image displaying surface ship wakes. The conventional multilook technique is used as a reference for the performance comparisons.

A part of a 4-look image obtained from an airborne SAR of the ONERA (Office National d'Etudes et de Recherches Aérospatiales) is shown on figure 1. It is a 400×400 pixel image. The resolution is 2.9m in ground range and 2.9m in azimuth. It displays a ship wake (right hand side of the image), which represents the texture to enhance. To obtain this image, four looks have been projected on the same geographic plane and summed in intensity.

Figure 2 shows the 4-look image obtained with our technique, using the complex looks. The speckle noise has been reduced, but the contrast has been degraded. The 4-look image obtained with our technique, using amplitude looks, is presented on figure 3. In this case, speckle has been reduced significantly. The wake has been well enhanced and can be now better distinguished.

The difference of results for the two methods may come from the fact that the correlation existing between the inphase and quadrature components of two different looks is less important than the correlation existing between two different amplitude looks.

5. CONCLUSION

A multilook technique using the phase and correlation or just the correlation - informations existing between the looks has been presented. It allows to enhance a specific feature in the image while reducing speckle when using amplitude looks. Effectively, preliminary results shows that it performs better for the case of amplitude looks than for complex looks. An improvement of this technique will consist in finding robust noise models instead of choosing it in homogeneous regions. This can also be done for the texture. We are currently studying the performance of the technique on images displaying wakes less visible than those presented in this paper.



Figure 1. Original 4-look image



Figure 2. Resulting image for the complex case



Figure 3. Resulting image for the amplitude case

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