Discrete Interference Suppression in Non-homogeneous Clutter Using D^3-STMB Hybrid STAP Algorithm

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1. Introduction

Space-Time Adaptive Processing (STAP) [1] is a most commonly used signal processing technique for target detection in radar systems, which can effectively suppress the strong clutter and detect the targets from a moving platform. However, the fully adaptive STAP algorithm is very difficult to be implemented for the practical system because of the huge computations and too many samples required for the covariance matrix estimation [2]. The Joint-Domain Localized (JDL) [5] and ΣΔ-STAP [6] algorithms have been proposed as the suboptimal STAP algorithms, which have the small system degrees of freedom (DoFs) and can reduce the computations and sample requirement dramatically. However, those existing STAP algorithms can not correctly detect the targets in the primary range cell for the non-homogeneous clutter environment, specifically when there is a discrete interference [3], because the information of the discrete interference is not contained in the training samples of those algorithms. In order to solve this problem, a non-statistical direct data domain (D^3) method has been proposed to suppress the discrete interference in the primary range cell [7]. However, the performance of the D^3 method in suppressing the correlated clutter is inferior to the statistical STAP algorithms [4]. Consequently, the hybrid algorithm of the D^3 method and the statistical JDL algorithm has been proposed to remove the discrete interferences in non-homogeneous clutter [3, 9]. However, if there is some array element error in the system, the Localized Processing Region (LPR) in JDL algorithm should be expanded in the spatial domain so that the computations of the D^3-JDL hybrid method will be increased significantly. It has been well known that the space-time multiple-beam (STMB) algorithm [8] is robust to array element error and the computations and the sample requirement of which are much smaller than the JDL algorithm. Therefore, a new hybrid method of the D^3 method and the STMB algorithm is proposed to suppress the discrete interference in non-homogeneous clutter environment in this paper.

This paper is organized as follows. The fundamentals of STAP algorithm are introduced in Section 2. The new hybrid D^3-STMB algorithm is presented in Section 3 and the simulation results are given in Section 4. The conclusion is summarized in Section 5.

2. Space-Time Adaptive Processing (STAP) Fundamentals

An N-element uniformly spaced linear array is considered. The array spacing between each antenna element is a half of wavelength. The received data from the N receiving elements due to the K pulses in one coherent processing interval (CPI) can be denoted by an $N \times K$ matrix $\mathbf{X}$. $\mathbf{X}(n, k)$ denotes the echo signal received by the nth element at time k ($n = 1, 2, ..., N$, $k = 1, 2, ..., K$). By stacking the columns of $\mathbf{X}$ to form a $NK \times 1$ vector $\mathbf{x}$ which is a space-time snapshot and denoted by

$$\mathbf{x} = [\mathbf{X}(1,1), \mathbf{X}(2,1), ..., \mathbf{X}(N,1), \mathbf{X}(1,2), ..., \mathbf{X}(N,2), ..., \mathbf{X}(N,K)]^T \quad (1)$$

where T denotes the transpose operation.

It is well know that the weighting vector of the fully adaptive STAP processor [4] is given by

$$\mathbf{w} = \frac{\mathbf{R}_{\mathbf{x}}^{-1}\mathbf{s}}{\mathbf{s}^H \mathbf{R}_{\mathbf{x}}^{-1}\mathbf{s}} \tag{2}$$

where $\mathbf{s}(\phi_t, f_t) = \mathbf{s}_t(f_t) \otimes \mathbf{s}_s(\phi_t)$ is the target steering vector and $\mathbf{R}_{\mathbf{x}} = E\left[\mathbf{x}\mathbf{x}^H\right]$ is the covariance matrix of clutter and noise. H and $\otimes$ represent the conjugate transpose operation and the Kronecher product, respectively.

$$\mathbf{s}_t(f_t) = [1 \quad z_t^i \quad \cdots \quad z_t^{(K-1)}]^T, z_t = e^{j\frac{2\pi f_t}{f_R}} \tag{3}$$

$$\mathbf{s}_s(\phi_t) = [1 \quad z_s^i \quad \cdots \quad z_s^{(N-1)}]^T, z_s = e^{j\frac{2\pi d}{\lambda}\sin\phi_t} \tag{4}$$

The fully adaptive STAP algorithm is very difficult to be implemented for the practical system because of the huge computations and too many samples required for the covariance matrix estimation [2]. In order to overcome these problems, many suboptimal reduced-dimension STAP algorithms [4] have been proposed.

3. New Hybrid STAP Algorithm

In this paper, a new hybrid STAP algorithm of the D^3 method and the STMB algorithm is proposed to suppress the discrete interference in non-homogeneous clutter environment, which has the advantages of both non-statistical and statistical algorithms. The statistical STMB algorithm [8] is applied to suppress the correlated clutter, while the D^3 method [7] is used to remove the discrete interference in the primary range cell.

In the proposed hybrid STAP algorithm, the optimum weights of STMB processing for the ith Doppler channel and jth beam can be expressed by

$$\mathbf{w}_{STMB} = \frac{(\mathbf{T}_L^H \mathbf{R}_{\mathbf{x}} \mathbf{T}_L)^{-1}\mathbf{s}_L}{\mathbf{s}_L^H (\mathbf{T}_L^H \mathbf{R}_{\mathbf{x}} \mathbf{T}_L)^{-1}\mathbf{s}_L} \tag{5}$$

where $\mathbf{s}_L$=$\mathbf{T}^H\mathbf{s}$. $\mathbf{T}_L$ is a transform matrix, which is given by

$$\begin{aligned}\mathbf{T}_L = \Big[& [\mathbf{S}_t(f_{ti}) \otimes \mathbf{S}_s(\phi_{tj})]^T, [\mathbf{S}_t(f_{ti}) \otimes \mathbf{S}_s(\phi_{t1})]^T, [\mathbf{S}_t(f_{ti}) \otimes \mathbf{S}_s(\phi_{t2})]^T, \cdots, \\ & [\mathbf{S}_t(f_{ti}) \otimes \mathbf{S}_s(\phi_{tq})]^T, [\mathbf{S}_t(f_{t1}) \otimes \mathbf{S}_s(\phi_{tj})]^T, [\mathbf{S}_t(f_{t2}) \otimes \mathbf{S}_s(\phi_{tj})]^T, \cdots, [\mathbf{S}_t(f_{tp}) \otimes \mathbf{S}_s(\phi_{tj})]^T \Big]\end{aligned} \tag{6}$$

where p is the number of adjacent channels of the detected Doppler channel, q is the number of the adjacent beams of the mainbeam and the dimension of $\mathbf{T}_L$ is $NK\times(p+q+1)$. In the following, the D^3 method is used to form $\mathbf{T}_L$ for STMB processing. $\mathbf{T}_L$ is constructed as

$$\begin{aligned}\mathbf{T}_L = \Big[& [\mathbf{w}_{D3}(\phi_{tj}, f_{ti})]^T, [\mathbf{w}_{D3}(\phi_{t1}, f_{ti})]^T, [\mathbf{w}_{D3}(\phi_{t2}, f_{ti})]^T, \cdots, \\ & [\mathbf{w}_{D3}(\phi_{tq}, f_{ti})]^T, [\mathbf{w}_{D3}(\phi_{tj}, f_{t1})]^T, [\mathbf{w}_{D3}(\phi_{tj}, f_{t2})]^T, \cdots, [\mathbf{w}_{D3}(\phi_{tj}, f_{tp})]^T \Big]\end{aligned} \tag{7}$$

$$\mathbf{w}_{D3}(\phi_t, f_t) = \begin{bmatrix} \mathbf{w}_t \\ 0 \end{bmatrix} \otimes \begin{bmatrix} \mathbf{w}_s \\ 0 \end{bmatrix} \tag{8}$$

where $\mathbf{w}_{D3}(\phi_t, f_t)$ is the space-time adaptive weight vector of D^3 processing, the dimension of which is $NK\times 1$. The temporal weights $\mathbf{w}_t$ and the spatial weights $\mathbf{w}_s$ are the eigenvectors corrosponding to the maximum eigenvalue of $[\mathbf{s}_{t(0:K-2)}\mathbf{s}_{t(0:K-2)}^H - \mathbf{B}^T\mathbf{B}^*]$ and $[\mathbf{s}_{s(0:N-2)}\mathbf{s}_{s(0:N-2)}^H - \mathbf{A}^T\mathbf{A}^*]$, respectively. $\mathbf{s}_{t(0:K-2)}$ is the first K-1 entries of the temporal steering vector, and $\mathbf{s}_{s(0:N-2)}$ is the first N-1 entries of the spatial steering vector, $\mathbf{A}$ and $\mathbf{B}$ are denoted by

$$\mathbf{A} = \begin{bmatrix} \mathbf{x}_{00} - z_s^{-1}\mathbf{x}_{10} & \mathbf{x}_{10} - z_s^{-1}\mathbf{x}_{20} & \cdots & \mathbf{x}_{(N-2)0} - z_s^{-1}\mathbf{x}_{(N-1)0} \\ \mathbf{x}_{01} - z_s^{-1}\mathbf{x}_{11} & \mathbf{x}_{11} - z_s^{-1}\mathbf{x}_{21} & \cdots & \mathbf{x}_{(N-2)1} - z_s^{-1}\mathbf{x}_{(N-1)1} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{x}_{0(K-1)} - z_s^{-1}\mathbf{x}_{1(K-1)} & \mathbf{x}_{1(K-1)} - z_s^{-1}\mathbf{x}_{2(K-1)} & \cdots & \mathbf{x}_{(N-2)(K-1)} - z_s^{-1}\mathbf{x}_{(N-1)(K-1)} \end{bmatrix}_{K\times(N-1)} \tag{9}$$

$$\mathbf{B}=\begin{bmatrix} \mathbf{x}_{00}-z_t^{-1}\mathbf{x}_{01} & \mathbf{x}_{01}-z_t^{-1}\mathbf{x}_{02} & \cdots & \mathbf{x}_{0(K-2)}-z_t^{-1}\mathbf{x}_{0(K-1)} \\ \mathbf{x}_{10}-z_t^{-1}\mathbf{x}_{11} & \mathbf{x}_{11}-z_t^{-1}\mathbf{x}_{12} & \cdots & \mathbf{x}_{1(K-2)}-z_t^{-1}\mathbf{x}_{1(K-1)} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{x}_{(N-1)0}-z_t^{-1}\mathbf{x}_{(N-1)1} & \mathbf{x}_{00}-z_t^{-1}\mathbf{x}_{(N-1)2} & \cdots & \mathbf{x}_{(N-1)(K-2)}-z_t^{-1}\mathbf{x}_{(N-1)(K-1)} \end{bmatrix}_{N\times(K-1)} \quad (10)$$

Two stage processing is applied in the proposed D^3-STMB hybrid method. Firstly, the D^3 method is used to remove the discrete interference in the primary range cell in nonhomogeneous clutter. Secondly, the STMB algorithm is applied to suppress the correlated clutter, the most processing of which is similar to the original JDL algorithm [3].

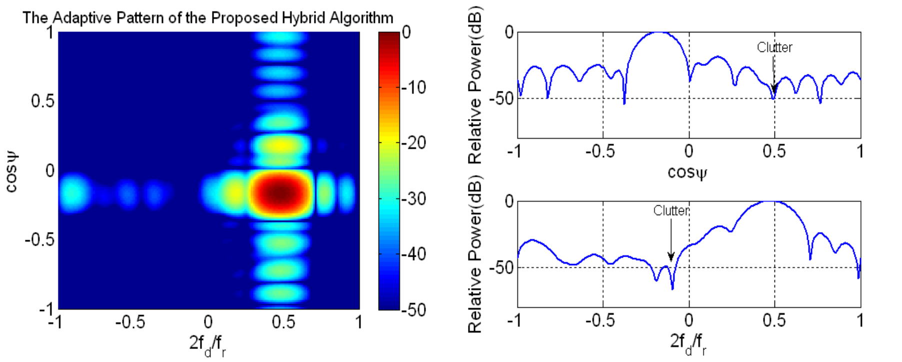
4. Simulation Results

In order to verify the validity of proposed D^3-STMB hybrid STAP method, the simulation is carried out. In the simulation, 4 Doppler bins and 4 angle bins around the look direction are assumed in STMB algorithm to construct a cross shape. Therefore, the total of DoFs is 9. In order to estimate the covariance matrix exactly, it is required at least 18 range cells. The SNR of echo signal from target is assumed to be 30 dB in the range bin 150 and the normalized Doppler frequency is 0.48. When the clutter environment is non-homogeneous, the INR of the strong discrete interference is assumed to be 30 dB in the same range bin where the target presents and the normalized Doppler frequency of interference is 0.32. The other simulation parameters are shown in Table 1.

Table 1: Parameters in Simulation

Parameter	Value	Parameter	Value
Number of Elements	14	Number of Pulses	16
Array spacing	0.335m	PRF	625Hz
Height of platform	9000m	Platform velocity	100m/s
Look Direction	0deg	CNR(clutter)	60dB

The adaptive pattern of the proposed D^3-STMB hybrid method is shown in Fig. 1. It can be obsered that the target is located in -0.17 azimuth and 0.48 normalized Doppler frequency in Fig. 1 (a). The adaptive pattern has a slants null that spans the clutter ridge, thereby the mainlobe and sidelobe clutters have been supressed effectively. Two principle plane cuts of the adaptive pattern at target location are respectively shown in Fig. 1 (b). In the first plane cut, it has been found that a null is formed to suppress the sidelobe clutter in 0.48 normalized Doppler frequency. In the second plane cut, it has been found that deep clutter null is formed to suppress the mainlobe clutter in -0.17 azimuth. These results have shown that the proposed method can effectively suppress the mainlobe and sidelobe clutters.



(a) Adaptive pattern

(b) Principle plane cuts at target location

Figure 1: Adaptive pattern of the proposed D^3-STMB hybrid method

The Modified Sample Matrix Inversion (MSMI) result of proposed hybrid method to suppress the discrete interference is shown in Fig. 2. It has been found that the target can be detected clearly. When there is a discrete interference in the non-homogeneous clutter, the proposed method is much more effective than the STMB algorithm, because the D^3 method is applied to remove the discrete interference by maximizing the gain in the target Doppler and minimizing the gain in the interference Doppler.

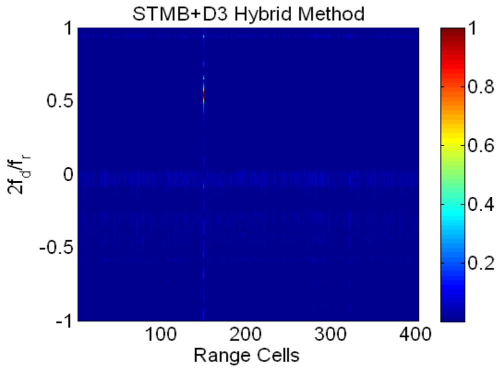


Figure 2: MSIM result of the proposed hybrid method to suppress the discrete interference

5. Conclusion

This paper presents a new hybrid STAP method by combining of the D^3 method and the STMB algorithm, which can remove effectively the discrete interference in the non-homogeneous clutter environment. In the proposed method, the D^3 method is used to remove the discrete interference in the primary range cell and the statistical STMB algorithm is used to suppress the residual clutters. The performance of proposed method has been demonstrated by the simulation.

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