An Adaptive Array Antenna Using Blind Extraction of Signal Subspace for Radar

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1. Introduction

Jamming is a serious issue for radar systems and it should be paid significant efforts to mitigate its effects. For the purpose to suppress the jammer which has high power, it is effective to apply the adaptive array antenna [1]. The power inversion adaptive array (PIAA) [2] is useful to suppress the high power interferences because it does not require detailed information about the desired signal waveform or arrival angle. However, the number of degrees of freedom in the array must be chosen to equal the number of interfering signals. Also, PIAA don't perform the beam steering to the direction of the desired signal, so the performance of PIAA is not as good as that of the MMSE (Minimum Mean Square Error) adaptive array [3] when the angle difference between the desired signal and interference is small. MSN (Maximum Signal-to-Noise ratio) adaptive array [4] is well-known as Howells-Applebaum adaptive array and has been investigated about the use for radar system. Although MSN adaptive array can maximize the output SNR (Signal-to-Noise Ratio) in the array, the accurate array response vector is required. Therefore, it is important to study the jamming suppression techniques with blind processing in radar system.

In this paper, we propose the adaptive array antenna with blind extraction of signal subspace in radar system. The proposed method has two processes for jamming suppression and signal combining. First, it calculates the projection matrix, which projects the received signal vector onto the space orthogonal to the jammer signal subspace. The projection matrix consists of the eigen vectors obtained from the eigen decomposition of the correlation matrix. For the calculation, the snapshots are chosen from regions where the target signal is known to be absent. Next, the signal subspace of the target signal is extracted from the received signal vectors of array by the orthogonal projection using the projection matrix. Therefore, the maximal ratio combining of the target signal components can be performed by using the eigen vector corresponding the largest eigen value of the correlation matrix obtained from the output signal vector including the target signal. The effectiveness of the proposed method is confirmed by the computer simulation results.

2. Proposed Method

Fig.1 shows the configuration of the proposed method. The process of the proposed method has two steps which are jamming suppression and signal combining. This configuration is capable of the blind signal processing that does not require something about the target signal waveform. We assume that the number of waves is smaller than that of antenna elements. The array input signals at the k th antenna element is given by

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_K \end{bmatrix} = \mathbf{a}_S(\theta_S)s(m) + \begin{bmatrix} \mathbf{a}_J(\theta_{J1}) & \mathbf{a}_J(\theta_{J2}) & \cdots & \mathbf{a}_J(\theta_{JL}) \end{bmatrix} \begin{bmatrix} J_1(m) \\ J_2(m) \\ \vdots \\ J_L(m) \end{bmatrix} + \begin{bmatrix} n_1(m) \\ n_2(m) \\ \vdots \\ n_K(m) \end{bmatrix} \quad (1)$$

where $\mathbf{a}_S(\theta_S)$, $\mathbf{a}_J(\theta_{Jl})\ (l = 1,2,...,L)$ are the array response vector of the target signal and the jammers, respectively. $s(m)$, $J_l(m)$, $n_k(m)$ are the target signal, the jammers, and the white Gaussian noise. The m means sample number. The target signal and the jammers are statistically independent. Although there are the radar clutters which are coherent with the desired echo signal

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under real condition, those can be mitigated by the clutter suppression techniques such as MTI (Moving Target Indicator) [5]. Therefore, we focus to discuss about the jamming suppression in this paper.

The vector notation of the equation (1) is given by

$$\mathbf{X}(m) = \mathbf{a}_S(\theta_S)s(m) + A_J\mathbf{J}(m) + \mathbf{N}(m) \tag{2}$$

In radar, the snapshots can be easily obtained from regions where the target signal is known to be absent since the pulse signal transmission for the target is controlled by the receiver. Therefore, $\mathbf{X}_J$ which consists of the L jammer signals is given by

$$\mathbf{X}_J(m) = A_J\mathbf{J}(m) + \mathbf{N}(m) \tag{3}$$

2.1. Jamming Suppression

First, the correlation matrix of $\mathbf{X}_J(m), m = 1, \ldots, M_1$ is estimated by

$$R_J = \frac{1}{M_1}\sum_{m=1}^{M_1}\left\{\mathbf{X}_J(m)\mathbf{X}_J^H(m)\right\} \tag{4}$$

The relationship among the eigen values associated with the eigen decomposition of the correlation matrix is expressed as

$$\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_L \gg \lambda_{L+1} = \cdots = \lambda_K = \sigma^2 \tag{5}$$

where σ^2 is noise power. Therefore, the jammer subspace is

$$J = \sum_{j=1}^{L}\mathbf{e}_j\mathbf{e}_j^H \tag{6}$$

The projection matrix, P_J, which projects the received signal vector onto the space orthogonal to the jammer subspace is given by

$$P_J = I - J = I - \sum_{j=1}^{L}\mathbf{e}_j\mathbf{e}_j^H \tag{7}$$

where I is the $K \times K$ identity matrix [6]. For a given data vector $\mathbf{X}$, the jammer component can be nulled by forming

$$\mathbf{b} = P_J\mathbf{X} \tag{8}$$

This process equals to receive by the K multiple beams formed the null at the direction of the jammer, as be shown in Fig.2.

2.2. Signal Combining

The proposed method can improve the output SNR by combining the signal vector $\mathbf{b}$ because the signal subspace of the target is only extracted by the jamming suppression process. The correlation matrix R_S of the vector $\mathbf{b}(m), m = 1, \ldots, M_2$ is calculated as

$$R_S = \frac{1}{M_2}\sum_{m=1}^{M_2}\left\{\mathbf{b}(m)\mathbf{b}^H(m)\right\} \tag{9}$$

Let λ_1' be the largest eigen value associated with the eigen decomposition of the correlation matrix R_S, and let $\mathbf{e}_1'$ be the corresponding eigen vector. Using $\mathbf{e}_1'$ as the weight vector, it achieves the maximal ratio combining of the target signal.

$$y = \mathbf{W}^H\mathbf{b} = \mathbf{e}_1'^H\mathbf{b} \tag{10}$$

3. Simulation Results

In this section, we present simulation results illustrating the performance properties of the proposed method. A 16 element linear array is considered with a half-wavelength spacing where the element pattern is omni-directional. The DOA (direction of arrival) of the target signal is 0 degree (broadside direction) and the input power is 0dB. The number of jammer is one. The results of PIAA and MSN are also plotted for comparison.

3.1. IMF versus Snapshot Number

Fig.3 and Fig.4 show the IMF properties as a function of snapshot number when the input SNR is -10dB and -15dB, respectively. IMF (improvement factor) means the SINR improvement to the SINR of the single element case. The DOA of jammer is 5 degree and the input power is 50dB. Since we assume to apply the pulse compression techniques [7], the input SNR at an antenna element is low.

In Fig.3, when the snapshot number is over 100, the proposed method improves 9dB against PIAA and almost achieves the same IMF of MSN. Even if the input SNR is lower as be shown in Fig.4, the good performance is obtained by using many samples.

3.2. IMF versus DOA of Jammer

Fig.5 shows the IMF property as a function of DOA of jammer when the input SNR is -15dB. The snapshot number is 1000 and the input power of jammer is 50dB. When the angle difference between the target signal and the jammer is over 3 degree, the proposed method achieves good IMF property that is almost the same IMF of MSN. Therefore, despite the blind processing, the proposed method is useful to suppress the main beam jamming.

4. Conclusion

We have proposed the adaptive array antenna with blind extraction of signal subspace in radar system. First, the signal subspace of the target signal is extracted from the received signal vectors of array by using the projection matrix, which projects the received signal vector onto the space orthogonal to the jammer signal subspace. Next, the maximal ratio combining of the target signal components is performed by using the eigen vector corresponding the largest eigen value of the correlation matrix obtained from the output signal vector including the target signal. The effectiveness of the proposed method was confirmed by the computer simulation. The performance of the proposed method is better than that of PIAA.

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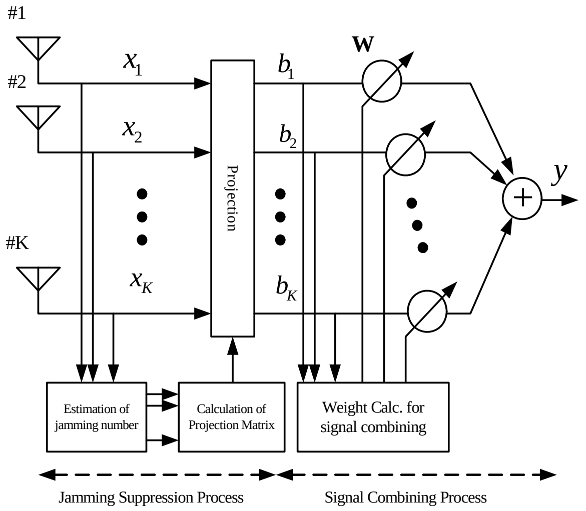

Fig.1 Configuration of the proposed method

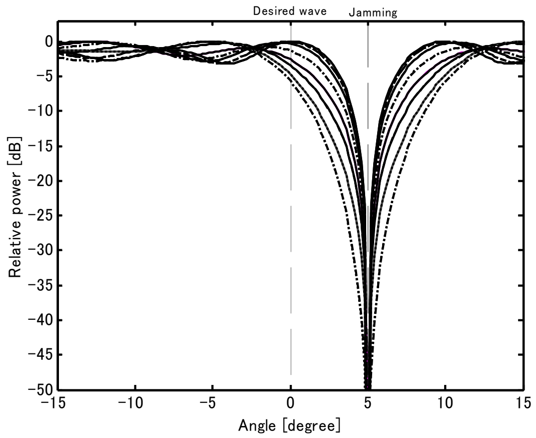

Fig.2 Beam patterns of projection matrix (16 element array, DOA of desired wave:0 [deg.], DOA of jammer: 5 [deg.])

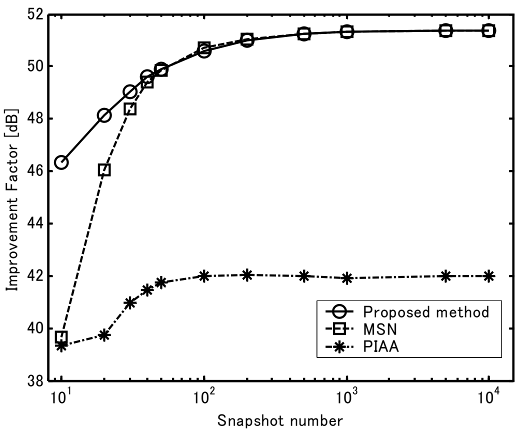

Fig.3 IMF versus snapshot number (Input SNR＝-10dB)

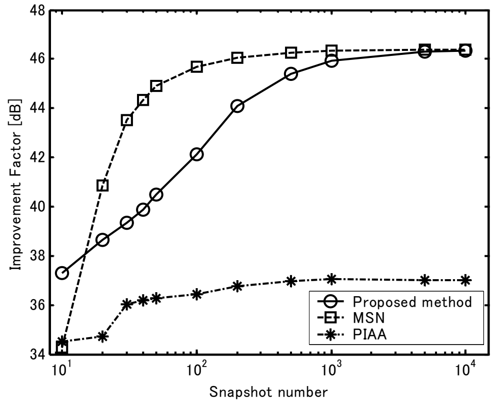

Fig.4 IMF versus snapshot number (Input SNR＝-15dB)

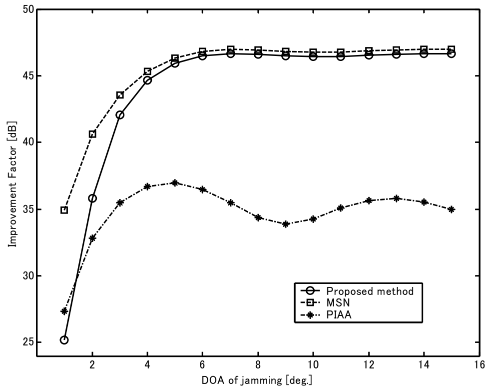

Fig.5 IMF versus DOA of jammer