Auxiliary polarization sensitive array (APSA) and performance analysis

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Abstract. In this paper, an auxiliary polarization sensitive array (APSA) model is proposed, which can reduce the cost of receiving polarization information and further improve the performance of the filter. On the basis of a single polarized linear array, a partial array element is selected to transform into an orthogonal dipole array element, so that the array has the ability to receive polarization information. At the same time a new steering vector and received signal model are constructed. Received signal is filtered based on that, and the filtering capability and performance of the array are analysed in detail. The computer simulation shows that the proposed array model can effectively improve the filtering performance of the traditional array. The simplified structure can effectively reduce the cost of the traditional polarization sensitive array on the premise of guaranteeing the signal to noise ratio of the receiving letter.

1. Introduction

The polarization sensitive array (PSA) [1] can receive multidimensional information in the polarization domain and space domain, which is better than the single polarized array [2]. It has been paid more and more attention and applied in the field of radar electronic warfare. The associated polarized space domain joint filter [3] method is developing rapidly.

Although PSA has an excellent performance, its application threshold is relatively high.

1. Antenna size limit [4-5]: polarization sensitive array structure is relatively complex, volume relatively large, and multiple signals will take up a certain volume;

2. Cost limitation [6-7]: compared to ordinary arrays, PSA complex antennas and signal channels make the cost doubles, but the performance improvement is limited, reducing the sex price. Ratio:

3. A large number of developed single polarized radar cannot make large scale full polarization transformation or high cost of transformation to the antenna. PSA cannot make a large number of single polarized radar have a certain polarization information processing capability. In order to save the cost, the combined filtering of the received signal is completed by the design of the polarization space orientation vector and the optimized polarization filtering algorithm [8-10]. The special flow pattern of the array makes the signal cannot be completely expressed in the form of four elements, and a beamforming algorithm more suitable for the array is considered.

2. Antenna and signal model

Figure 1 shows the proposed array model. The spacing of the array element is half a signal wavelength, first to i-1 and i+L to N points to the X axis, and the I to i+L-1 element is composed of the cross dipole, pointing to the X axis and the Y axis respectively. For linear array, the two-dimensional direction of arrival is \( (\varphi = 90^\circ, \theta) \), the polarization parameter is \( (\gamma, \eta) \), and its space steering vector is:
Its polarization steering vector is:

$$\mathbf{a}_p = \begin{bmatrix} \sin \phi, \cos \phi \cos \theta, \cos \phi \sin \theta \end{bmatrix}^T$$

(2)

All the array elements of the antenna can receive the signal of the horizontal polarization, and the \(i\) to \(i+L-1\) elements can receive the signal of the vertical polarization, and the space polarization domain guidance vector is constructed.

$$\mathbf{a}_d = [E_v \cdot \mathbf{a}_d^T, E_H \cdot \mathbf{a}_d^T]^T$$

(3)

where \(\mathbf{a}_d = [e^{j\pi(i-1)\sin \theta}, \ldots, e^{j\pi(i-L+2)\sin \theta}]^T\) is the space orientation vector of the cross dipole array element.

The receiving signal of the array is:

$$x(t) = \mathbf{a}_d \cdot s_d(t) + \sum_{j=1}^{J} \mathbf{a}_j \cdot s_j(t) + \mathbf{n}(t)$$

(4)

where \(s_d(t)\) is the target signal of the incident, \(a\) is similar to the \(a_d\) form. It is the spatial polarization domain guidance vector of interference in this array model, \(J\) is the number of interference sources, \(s_j(t)\) is the interference source of the incident, \(\mathbf{n}(t)\) is the additive Gauss white noise vector.

Unlike the conventional polarization sensitive array model, this model transforms the array element on the basis of the non polarized array, which makes the array have a certain polarization signal receiving ability and the cost is relatively low. The anti-interference performance of the array needs to be further analysed.

3. Array performance analysis

The output of the beamformer is the product of the weight vector and the output vectors of each array element.

$$y(t) = \mathbf{w}^H x(t)$$

(5)

According to minimum variance distortionless response(MVDR), weight vectors are designed according to the following criteria.

$$\min_{\mathbf{w}} \mathbf{w}^H \mathbf{R}_x \mathbf{w} \quad \text{s.t.} \quad \mathbf{w}^H \hat{\mathbf{a}}_d = 1$$

(6)

where \(\mathbf{R}_x = \mathbb{E}[x(t)x^H(t)]\) and \(\hat{\mathbf{a}}_d\) is the estimation of the guidance vector.

By using the Lagrange multiplier method, it can be solved as follows:

$$\mathbf{w}_{\text{MVDR}} = \mu \mathbf{R}_x^{-1} \hat{\mathbf{a}}_d$$

(7)

where \(\mu = (\mathbf{a}_d^H \mathbf{R}_x^{-1} \hat{\mathbf{a}}_d)^{-1}\) is a real number and does not affect output SINR.
In ideal cases, the output signal to interference plus noise ratio (SINR) of the array model is optimized through the optimal beamformer.

$$\text{SINR} = \rho_{s,n} \left[ \frac{|a_d^H a_d|^2}{\rho_{i,n}^2 + |a_d^H a_d|^2} \right]$$  \hspace{1cm} (8)

where $\rho_{s,n}$ is the received signal to noise ratio (SNR), $\rho_{i,n}$ is the received interference to noise ratio (SNR).

$$a_d^H a_d = E_s N \Gamma_s + E_i N \Gamma_i$$
$$= \cos^2 \gamma (1-e^{2j\phi}) + \cos^2\theta \sin^2 \gamma e^{2j\eta} (1-e^{2j\phi})$$
$$\approx N \cos^2 \gamma + L \cos^2 \theta \sin^2 \gamma e^{2j\eta}$$  \hspace{1cm} (9)

where $\phi = \pi \sin \theta$. The same reason can be obtained:

$$a_d^H a_j \approx N \cos \gamma \cos \gamma_j + L \cos \theta \cos \theta_j \sin \gamma \sin \gamma_j e^{j(n+\eta)}$$  \hspace{1cm} (10)

$$a_d^H a_j \approx N \cos^2 \gamma_j + L \cos^2 \theta \sin^2 \gamma_j e^{j(2\eta)}$$  \hspace{1cm} (11)

where $\gamma_j$, $\theta_j$ and $\eta_j$ are all interference parameters, corresponding to target signal parameters.

From formula (8) to formula (11), the output SINR of the array model is related to many conditions: the higher the SNR, the greater the difference between the interference and the target polarization parameters, the lower the INR, the more the same polarization and the array element, the higher the output SINR.

4 special cases are considered below.

1. There is no interference, that means $\rho_{i,n} = 0$, the output SINR is the same as $\rho_{s,n}(N \cos^2 \gamma + L \cos^2 \theta \sin^2 \gamma e^{j(2\eta)})$ the desired signal to noise ratio approximately equal to the number of elements in the direction of the main polarization and cross polarization in the array and the polarization mode of the echo signal.

2. There is interference whose direction is the same with target space, but with polarization difference, where $a_d^H a_j$ is relatively enlarged; the single polarized radar, whose $L = 0$, cannot separate the target from the interference area, and the output SINR is low, which cannot meet the needs of the detection target. In this model, whose $L \neq 0$, the output SINR can only be cut down and can still meet the needs of the detection target under certain conditions, which performs will. In fact, this is the case of radar's self-defensive jamming.

3. The interference polarization is the same as the target polarization, and there is a difference in the spatial direction. At this time, the model degenerates into a single polarized array antenna model, which has almost the same filtering capability as the single polarized radar.

4. INR infinity, the output SINR is zero only when the spatial angle and polarization mode of interference and target, that is, the guidance vector of the interference and the target, and the linear correlation.

4. **Simulation and analysis**

This section verifies the applicability of the antenna model and the effectiveness of the algorithm by computer simulation.

The array consists of 20 array elements, of which 5 are composed of cross-dipole polarization auxiliary array elements; the form of a signal is a binary phase coded signal. The estimated guidance vector has a certain spatial angle error and polarization error. There are two disturbances in the form of Gauss white noise. There is a certain distinction between the target signal in the space and the polarization domain. The specific setting of the simulation parameters is shown in table 1.
### Table 1. Detailed parameter setting.

| Parameter                                      | Value         |
|-----------------------------------------------|---------------|
| Number of elements of the antenna's main polarized array $N$ | 20            |
| Number of elements of the antenna's auxiliary polarized array $L$ | 5             |
| Signal SNR                                     | 15 dB         |
| Signal $\theta$                                | $15^\circ$    |
| Signal $\gamma$                                | $78^\circ$    |
| Signal $\eta$                                  | $45^\circ$    |
| Signal form                                    | binary phase coded |
| Steer vector error $\Delta \theta$             | $1.5^\circ$   |
| Steer vector error $\Delta \gamma$             | $4^\circ$     |
| Interference 1 INR                             | 30 dB         |
| Interference 1 $\theta$                       | $14^\circ$    |
| Interference 1 $\gamma$                       | $30^\circ$    |
| Interference 1 $\eta$                         | $75^\circ$    |
| Interference 2 INR                             | 30 dB         |
| Interference 2 $\theta$                       | $17^\circ$    |
| Interference 2 $\gamma$                       | $45^\circ$    |
| Interference 2 $\eta$                         | $25^\circ$    |

**Figure 2.** Output SINR of APSA and single polarization array.

The result is shown in figure 2. The APSA performs about 15 dB better than the single polarization array, which approves the effectiveness of this method.

The figure 3 shows the system output SINR with different elements number of the antenna's auxiliary polarized array $L$. Discuss the following cases:

1. When the number of auxiliary array elements is $L=0$, that means, the array model is a single polarization array, and the output result is not improved.

2. $L=1$, due to the introduction of polarization information, the performance of the system has been greatly improved. It can be seen that the partial polarization of the radar antenna can improve the performance of the system quickly on the premise of controlling the cost.

3. $1 < L \leq N$, with the increase of the number of auxiliary array elements, the performance of the system is also continuously optimized. At the same time, the increase of the signal path, the increase of cost, the increase of noise and the increase of the complexity of the algorithm. At that time, the array model was equivalent to the conventional polarization sensitive array model.
The following is a special case: the space position of the target and the interference is the same, and the usual radar main lobe interference belongs to this class. The reason is that the spatial resolution of the radar is limited and the target signal cannot be separated from the interference area. The conventional single polarization radar cannot complete the elimination of such interference by pure spatial filtering, and the APSA with the ability of processing polarization information can be used. The spatial angle of interference 1 is 15 degrees, the interference polarization parameters change from 0 to 90 degrees, the interference 2 zero, the 100 sampling points and the other conditions unchanged. The result is shown in figure 4.

In the case of the same space angle, the system is filtered in pure polarization domain. When the difference between the target and the interference polarization parameters is large enough (>30 degree), the output SINR of the system can reach more than 10 dB, which basically satisfies the anti-interference demand. The greater the difference between the interference and the target polarization, the better the performance of the filtering performance.
5. Conclusions
In this paper, we propose the APSA model and the corresponding received signal model, and analyse its performance. Simulation results have shown its effectiveness. APSA can reduce the cost of receiving polarization information, and can effectively improve the anti-jamming performance.

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