A BSS-Based Sum-difference Four-channel Algorithm for Suppressing Multiple-Mainlobe Jammings

ZHOU Bi-lei $^1$, LI Rong-feng$^1$, SHAO Yin-bo$^1$, CAI Guan$^1$ and GUAN Wei$^1$

$^1$Air Force Early Warning Academy, Wuhan 430019, China

*zhoubilei666888@sina.com

Abstract. The target signal loss seriously when jamming enters into mainlobe. The existing studies can only suppress one MLJ. Hence, this paper proposes a BSS-based sum-difference four-channel algorithm for suppressing multiple-mainlobe jammings (Multiple-MLJs). The inputs channels are consisted of sum-difference four-channel. According to the statistical independence, the target and MLJ can be separated by adopting the BSS. A remark feature of the proposed approach is that it does not require priori knowledge about the real target or jammings, and it is easy to implement for engineering applications.

1. Introduction

In recent years, the US military has begun to equip EA-18G aircraft, which gradually replace EA-6B. EA-18G is not only the strongest electronic jammer, but also the strongest attack aircraft. It will be the major airborne electronic attack resources of US Navy in the future. What is more, EA-18G can fly by attack aircraft. Therefore, mainlobe jamming (MLJ) is a severe threat to radar. In generally, the MLJ has two types. The first is self-defensive jamming, which comes from the target. The second enters into the radar mainbeam, whose direction is different with the target, so we can call it as near-mainlobe jamming. In this paper, near-mainlobe jamming is called mainlobe jamming (MLJ) for short. At present, there are many technologies for suppressing self-defensive jamming [1-6]. However, they are not effective to suppress the MLJ. The sum-difference mainlobe canceller (MLC) [7] can suppress the MLJ effectively. Kai-Bor Yu et al. introduced another adaptive monopulse angle estimation algorithm, composed of ADBF and MLC [8-9]. Two anti-jamming algorithms which combine the sum-difference and auxiliary beam were proposed in [10-11]. However, those methods can only suppress one MLJ.

The BSS approach is recovering a number of unobserved signals from observed mixtures. At present, many researchers have done some works based on the BSS technology for suppressing the MLJ. The Fast ICA (independent component analysis) algorithm based on negative entropy maximization proposed in [12] and the joint approximation diagonalization (JADE) algorithm proposed in [13-15] are more widely used at present. However, these methods can only suppress one MLJ as [7-11]. In this paper, we propose a BSS-based sum-difference four-channel algorithm for suppressing multiple-MLJs.

2. The basic principle of the BSS

We consider the problem where $M$ independent non-stationary signals are received by an array of $N$ ($N \geq M$) channels. The classical narrowband signal model is used:
is the vector of the channel outputs, \( s(t) \in \mathbb{C}^{N \times 1} \) is the signal vector and \( r(t) \in \mathbb{C}^{K \times 1} \) is the white Gaussian noise vector. The unknown mixed matrix \( H \in \mathbb{C}^{N \times K} \) maps the source signals to the channel outputs, and is assumed to be of full column rank.

Given \( K \) snapshots, \( \{x(n)\}_{n=1}^{K} \), of the array output vector, the problem is to estimate the mixed matrix \( H \), where \( HB \) is essentially equal to the identity matrix, i.e. \( HB = PD \) where \( P \) is a permutation matrix and \( D \) is a non-singular diagonal matrix.

3. Mixed signal model

This paper considers rectangular array which has \( N_2 \) columns, and each column has \( N_1 \) elements, shown as figure 1. The distance between the elements in the direction of \( x \) and \( y \) is \( d \), the wavelength of the transmitted signal is \( \lambda \). \( \theta \) means the azimuth angle of signal, and \( \phi \) means the elevation angle of signal. Assuming there exist \( M \) signals \( s(t) = [s_1(t), s_2(t), ..., s_M(t)]' \in \mathbb{C}^{M \times 1} \), located at \( (\theta_m, \phi_m) (m = 0, 1, ..., M, M \leq 3) \).

This paper considers sum-difference four beams as input channels, containing of sum beam \( \Lambda_s \), azimuth difference beam \( \Lambda_d \), elevation difference beam \( \Lambda_{\phi} \) and double difference beam \( \Lambda_{\phi} \). Hence, the total number of channels is four, which must be larger than the number of signals, that is \( M \leq 4 \). And the mixed \( H \) is

\[
H = \begin{bmatrix}
w_z \quad a(\theta, \phi) \quad w_z \quad a(\theta, \phi) \quad \ldots \quad w_z \quad a(\theta, \phi) \\
\vdots \\
\end{bmatrix} = \begin{bmatrix}
c_{1,0} & c_{1,1} & \ldots & c_{1,M-1} \\
c_{2,0} & c_{2,1} & \ldots & c_{2,M-1} \\
\vdots \\
c_{4,0} & c_{4,1} & \ldots & c_{4,M-1} \\
\end{bmatrix}_{4 \times M}
\]

(2)

where \( a(\theta, \phi) \in \mathbb{C}^{N \times 1} \) is the direction vector of the \( m \) th signal \( s_m(t) \), and \( a(\theta, \phi) = a(\phi) \otimes a(\theta) \). The symbol \( \otimes \) is Kronecker product. \( a(\phi) = [1, e^{-i\alpha \phi}, \ldots, e^{-i(K-1)\phi}] \), \( a(\theta) = [1, e^{-i\beta \theta}, \ldots, e^{-i(K-1)\beta}] \), \( \alpha = 2\pi d \sin \phi / \lambda \), \( \beta = 2\pi d \cos \theta \cos \phi / \lambda \), \( w_z \in \mathbb{C}^{N \times 1} \) is the weighting vector of sum beam, \( w_{\phi} \in \mathbb{C}^{N \times 1} \) is the weighting vector of elevation.
difference beam, \( w_{x_x} \in \mathbb{C}^{N_1 \times 4} \) is the weighting vector of azimuth difference beam, and \( w_{z_y} \in \mathbb{C}^{N_1 \times 4} \) is the weighting vector of double difference beam.

\[
\begin{align*}
\mathbf{w}_z &= \left( \mathbf{w}_{\text{Taylor}_y} \otimes \mathbf{a}(\varphi_y) \right) \otimes \left( \mathbf{w}_{\text{Taylor}_x} \otimes \mathbf{a}(\varphi_x) \right) \\
\mathbf{w}_{x_x} &= \left( \mathbf{w}_{\text{Taylor}_y} \otimes \mathbf{a}(\varphi_y) \right) \otimes \left( \mathbf{w}_{x_x} \otimes \mathbf{a}(\theta_s) \right) \\
\mathbf{w}_{x_y} &= \left( \mathbf{w}_{\text{Taylor}_y} \otimes \mathbf{a}(\varphi_y) \right) \otimes \left( \mathbf{w}_{\text{Taylor}_x} \otimes \mathbf{a}(\theta_s) \right) \\
\mathbf{w}_{y_y} &= \left( \mathbf{w}_{x_y} \otimes \mathbf{a}(\varphi_y) \right) \otimes \left( \mathbf{w}_{\text{Taylor}_x} \otimes \mathbf{a}(\theta_s) \right)
\end{align*}
\]

(3)

where \( \mathbf{w}_{\text{Taylor}_y} \in \mathbb{C}^{N_1 \times 4} \) and \( \mathbf{w}_{x_x} \in \mathbb{C}^{N_1 \times 4} \) is the Taylor vector and Bayliss vector in the direction of \( x \), \( \mathbf{w}_{\text{Taylor}_y} \in \mathbb{C}^{N_1 \times 4} \) and \( \mathbf{w}_{x_y} \in \mathbb{C}^{N_1 \times 4} \) is the Taylor vector and Bayliss vector in the direction of \( y \). The symbol \( \otimes \) is Hadamard product.

4. Algorithm principle
The algorithm principle of this paper is shown as figure 2.

![Figure 2. The algorithm procedure](image)

The steps of the new algorithm:
(1) Mixed process: \( x(n) = Hx(n) + v(n) \).

where \( x(n) \) is the digitized mixed signal of \( x(t) \).

(2) Whitening process: \( z(n) = Wx(n) \).

where \( W \) is the whitening matrix, obtained by the subspace of covariance matrix:

\[
R_{xx} = \frac{1}{4} \sum_{k=1}^{4} x(n)x^H(n) \in \mathbb{C}^{4 \times 4}
\]

(4)

\[
W = \begin{bmatrix} (\mu_0 - \sigma^2)^{-1/2} g_0, (\mu_1 - \sigma^2)^{-1/2} g_1, \ldots, (\mu_{M-1} - \sigma^2)^{-1/2} g_{M-1} \end{bmatrix}^H
\]

(5)

where \( \mu_0, \mu_1, \ldots, \mu_{M-1} \) is the large eigenvalue, \( g_0, g_1, \ldots, g_{M-1} \) is the corresponding eigenvector. And \( \sigma^2 \) is the nosie variance estimation, which equals to the average of the remaining eigenvalue.

Whitening signal \( z(n) \) can also be expressed as:

\[
\begin{align*}
z(n) &= Wx(n) = WHs(n) + Wv(n) \\
&= Us(n) + Wv(n)
\end{align*}
\]

(6)

Obviously, in order to restore the signal \( S(n) \), unitary matrix \( U \) should be estimated.

(3) Four-order cumulant matrix: \( \mathcal{Q}_z(\Omega) \in \mathbb{C}^{N \times M} \).

\[
[\mathcal{Q}_z(\Omega)]_{i,j} = \sum_{\ell=1}^{M} \sum_{\delta=1}^{M} K_{\ell\delta}(z)^* \Omega_{\ell \delta}; \quad i, j \in [1, 2, \ldots, M]
\]

(7)
where \( \Omega_{kl} \) is one element of the matrix \( \Omega \in \mathbb{C}^{M \times H} \), \( \Omega_{kl} = \Omega (k,l) \),

\[
K_{w}(z) = cums(z_{w}(n), z_{w}^{*}(n), \ldots),
\]

\( z_{w}(n) \) is the \( w \)-th row of \( z(n) \), \( cums(\cdot, \cdots, \cdot) \) is the four-order cumulant operation.

(4) Estimate the unitary matrix \( \hat{U} \): the estimated unitary matrix \( \hat{U} \in \mathbb{C}^{M \times H} \) is obtained by characteristic decomposition as \( \Theta_{w}(\hat{\alpha}) = \hat{U} \Sigma \hat{U}^{\dagger} \), where \( \Sigma \in \mathbb{C}^{M \times H} \) is a diagonal matrix.

(5) Signal separation: \( \hat{s}(n) = \hat{U} \hat{z}(n) \).

(6) Pulse pressure:

\[
y(n) = conv\{\hat{s}(n), z_{w}^{*}(-n)\}
\]

(8) where \( conv(\cdot, \cdot) \) is convolution operation, \( y(n) \) is the outputs. By peak detection, the target can be obtained.

5. Simulation

Consider a rectangular planar array which has 48 columns, and each column has 22 elements, placed half a wavelength apart. The transmission signal is LFM signal, bandwidth is \( 5 \text{MHz} \), pulse width is 20\( \mu \text{s} \), and sampling rate is 20\( \text{MHz} \). The sumbeam static weight in the direction of elevation and azimuth is sampled for -35dB of Chebyshev. The difference beam static weight in the direction of azimuth is sampled for -35dB of Bayliss. The boresight of sumbeam is \( (90^\circ, 30^\circ) \). The 3dB sumbeam width along azimuth and elevation are 3.2\(^\circ\) and 7.1\(^\circ\) respectively. The incoming angle of the target with -11dB is located at \( (90^\circ, 30^\circ) \) and the 3000th sampling point. The noise in each channel follows additive white Gauss noise.

Simulation 1: one target and three MLJs.

Simulation conditions: The incoming angle of the three MLJs with 50dB is located at \( (90.8^\circ, 30^\circ) \), \( (90^\circ, 31.775^\circ) \), \( (89.2^\circ, 30^\circ) \), which is located at the one quarter of 3dB beam width (along the azimuth and elevation direction).

Figure 3 shows the outputs of the sum-different four channels by pulse pressure, where we cannot find the target.

![Figure 3. mixed signal with pulse pressure](image)

Figure 4 shows the signal separation result by the new algorithm, where the target is obtained.
When the MLJs are closer with the target, coming from \((89.6^\circ, 30^\circ), (90.4^\circ, 30^\circ), (90.4^\circ, 31^\circ)\), located at one eighth of 3dB beam width, the target still can be obtained in the figure 5. Hence, the new algorithm can be applied to more severe mainlobe jamming environment.

Simulation 2: one target, one mainlobe dense false-target (MDFJ) and two MLJs.

The simulation conditions: The incoming angle of the two MLJs with 50dB is located at \((90.8^\circ, 30^\circ), (90^\circ, 31.775^\circ)\), and the MDFJ with -5dB is located at \((89.2^\circ, 30^\circ)\). These jammings are all located at the one quarter of 3dB beam width. And the MDFJ located at the 2100th to 4000th sampling point.

Figure 6 shows the separation result by the new algorithm. Obviously, the target and MDFJ have been separated, and it is clearly that the channel 1 has the target signal.

6. Conclusions
Mainlobe jamming is still a severe problem in the anti-jamming field currently. And the existing studies can only suppress one MLJ. In order to solve this problem, this paper proposes a BSS-based four-channel sum-difference algorithm for suppressing multiple-mainlobe jammings. According to the simulation result, the new algorithm can suppress multiple-MLJs and MDFJ effectively. Moreover, the new algorithm can be applied to more severe mainlobe jamming environment. And it is easy for implement in engineering. Hence, the algorithm of this paper has an important engineering application value.
References

[1] SHI Yanbin, ZHANG An, GAO Xianjun. Research on the influence of SSJ on the survivability of aerial attack aircraft [J]. Electronics Optics & Control, 2008, 15(6): 7-9.

[2] LI Yongzhen, WANG Guoyu, WANG Liandong, WANG Xuesong. Study on Polarization Cancellation Algorithm of Self-defensive Blanket Jamming Based on Radar Sidelobe—canceller Antenna [J]. SIGNAL PROCESSING, 2008, 24(5): 775-779.

[3] Liming Ding, Rongfeng Li, Yongliang Wang, Lingyan Dai, Fengbo Chen. Discrimination and identification between mainlobe repeater jamming and target echo by basis pursuit. IET radar, sonar & navigation, 2017, 11(1):11-20.

[4] Liming Ding, Rongfeng Li, Lingyan Dai, Fengbo Chen, Yongliang Wang. Discrimination and identification between mainlobe repeater jamming and target echo via sparse recovery. IET radar, sonar & navigation, 2017, 11(2):235-242.

[5] Liming Ding, Lingyan Dai, Rongfeng Li, Fengbo Chen, Yongliang Wang. Discrimination and identification of time-delay repeater jamming and target echo by basis pursuit. 2015 IET International Radar Conference, Hangzhou, China.

[6] LUO Shuangcai, TANG Bin. An Algorithm of Deception Jamming Suppression Based on Blind Signal Separation [J]. Journal of Electronics & Information Technology, 2011, 33(12): 2801-2806.

[7] S.P. Applebaum, R. Wasiewicz. Main beam jammer cancellation for monopulse sensors. Final technical report DTIC RADC-TR-86-267, 1984.

[8] Yu K B, Murrow D J. Adaptive digital beamforming for angle estimation in jamming [J]. IEEE Transactions on Aerospace Electronic Systems, 2001, 37(2): 508-522.

[9] Yu K B, Murrow D J. Combining sidelobe canceller and mainlobe canceller for adaptive monopulse radar processing. US Patent 6867726, B1 2005.

[10] LI Rongfeng, RAO Can, DAI Lingyan, WANG Yongliang. Combining sum-difference and auxiliary beam for adaptive monopulse in jamming. Journal of Systems Engineering and Electronics, 2013, 24(3): 372-381.

[11] ZHOU Bilei, LI Rongfeng, DAI Linyan, WANG Yongliang. Adaptive Monopulse Algorithm Based On Combining Sum-Difference And Auxiliary Beam For Anti-Jamming At Subarray Level [J]. Radar Science And Technology, 2014, 12(4): 379-388.

[12] WANG Wentao, ZHOU Qingsong, LIU Xinghua, LI Lei. A Study on Radar Mainlobe Jamming Suppression Based on Blind Source Separation of Fast ICA [J]. Modern Radar, 2015, 37(12): 40-48.

[13] WANG Jianming, WU Guangxin, ZHOU Weiguang. A Study on Radar Mainlobe Jamming Suppression Based on Blind Source Separation Algorithm [J]. Modern Radar, 2010, 32(10): 46-49.

[14] WANG Wentao, ZHANG Jianyun, LIU Xinghua, LI Lei. Radar Anti-mainlobe-Jamming Based on Blind Source Separation Algorithm of JADE [J]. Fire Control & Command Control, 2015, 40(9): 104-108.

[15] Cardoso J. F. Blind beamforming for non-Gaussian signals [J]. IEEE Proceedings -F. 1993, 140(6): 224-230.