Blind beamforming based on Multi-target SCORE with a DMP algorithm

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***Abstract*—One of blind adaptive beamformers, the spectral self-coherent restoral (SCORE) algorithm extracts the signal of interests (SOIs) using the cyclostationarity. When multiple signals exist, however, the multi-target SCORE (MT-SCORE) algorithm should be developed to separately extract each signal. In addition, to successfully deal with a newly emerging signal in multi-target conditions, the global convergence of the MT-SCORE's weight vectors must be ensured and it is also important to find an appropriate initial vector for fast convergence. In this paper, we incorporate the dominant mode prediction (DMP) algorithm to obtain the eigenvector corresponding to a maximum eigenvalue which is assigned to the initial vector for the SCORE algorithm. With this initial vector, we develop an MT-SCORE algorithm extracting multiple SOIs in parallel. Simulation results show that the proposed algorithm has better performance of interference elimination and fast convergence than the conventional cross-SCORE algorithm.**

Keywords*—Blind beamforming, cyclostationarity, multi-target self-coherent restoral (MT-SCORE), dominant mode prediction (DMP)

I. Introduction

Blind adaptive beamformer can be implemented by utilizing the signals' properties such as constant amplitude, periodic statistical characteristic, and high order cumulant [1-3]. Among them, we focus on the cyclostationarity-based blind adaptive beamformer. A cyclostationary signal has the statistical property of correlating with either a frequency-shift of itself or a complex-conjugate version [4], which can be used to extract the signal of interest (SOI) and to suppress the interference without knowing the direction of the desired signal [5]. A class of spectral self-coherent restoral (SCORE) algorithms has been developed for the cyclostationary signals and the first algorithm was the least-square SCORE (LS-SCORE). This algorithm generates a reference signal through a control vector for an arbitrary direction. The performance may be greatly influenced by the value of the arbitrarily set vector. A cross-SCORE algorithm, which was developed to overcome this problem of the LS-SCORE, also updates the control vector that can generate the clean reference signal from which the interference signal is removed. The cross-SCORE algorithm can achieve better results over the LS-SCORE in terms of both the convergence rate and the maximum signal-to-interference-and noise ratio (SINR) at the expense of the computational complexity [2][6]. These algorithms cover the situation for one SOI. If there are multiple signals that should be acquired all, they need to be extended to a multi-target SCORE (MT-SCORE) algorithm that can deal with multiple signals.

In this paper, we propose an MT-SCORE algorithm where the SCORE algorithms are constructed in parallel to isolate and to extract all signals. It is important that the output of each SCORE algorithm converges to a different signal. To achieve this, the dominant mode prediction (DMP) algorithm is incorporated to obtain initial beamforming vectors for the MT-SCORE algorithm [7]. Initial beamforming vector has deep null at the incident angle of existing interferences and high beamforming gain at the incident angle of a newly-emerging signal. It is expected that the convergence speed of the proposed algorithm is faster than the conventional SCORE algorithm.

This paper organized as follows: Section II briefly describes the property of signal cyclostationarity and introduces the cross-SCORE algorithm. The proposed algorithm is explained in Section III. Through simulation, the performance of the proposed algorithm is shown in Section IV. Finally, we conclude this paper in Section V.

II. The Spectral Self-Coherence Restoral

A. Signal Cyclostationarity

As digitally modulated signals have a carrier frequency and bandwidth, mean and autocorrelation of them have periodic characteristics which are called as cyclostationarity. When arbitrary signal $s(n)$ is spectrally self-coherent or conjugate self-coherent at a cyclic-frequency α, cyclic autocorrelation function and conjugate cyclic autocorrelation function have a nonzero value and can be defined as follows:

$$R_{\mathbf{xx}}^{\alpha}(n_0) = \langle \mathbf{x}\left(n+\tfrac{n_0}{2}\right)\mathbf{x}^{\mathrm{H}}\left(n-\tfrac{n_0}{2}\right)e^{-j2\pi\alpha n/fs}\rangle_{\infty}, \qquad (1)$$

$$R_{\mathbf{xx}^*}^{\alpha}(n_0) = \langle \mathbf{x}\left(n+\tfrac{n_0}{2}\right)\mathbf{x}^{\mathrm{T}}\left(n-\tfrac{n_0}{2}\right)e^{-j2\pi\alpha n/fs}\rangle_{\infty}, \qquad (2)$$

where $\mathbf{x}^{\mathrm{T}}(n)$ is transpose version of $\mathbf{x}(n)$, $\langle\cdot\rangle_{\infty}$ denotes infinite time-averaging.

In this paper, we consider a received signal of the linear array that consist of a SOI and an interference signal. This received signal can be expressed as

$$\mathbf{x}(n) = s_{SOI}(n)\mathbf{a}(\theta_{SOI}) + s_{int}(n)\mathbf{a}(\theta_{int}) + \mathbf{n}(n), \tag{3}$$

where $\mathbf{a}(\theta)$ denotes the steering vector and $\mathbf{n}(n)$ represents a noise signal. If cyclic-frequencies of the signal of interest $s_{SOI}(n)$ and interference signal $s_{int}(n)$ are different, these signals have low correlation.

A blind-based interference cancellation algorithm using these characteristics is called spectral self-coherence restoral (SCORE) algorithm [2]. The main advantage of SCORE algorithm is that only required variable is the cyclic-frequency of the SOI, which is calculated from the symbol rate or the carrier frequency.

B. The cross-SCORE algorithm

We define a reference signal $r(n)$ as

$$r(n) = \mathbf{c}^{\mathrm{H}}\mathbf{u}(n), \tag{4}$$

$$\mathbf{u}(n) = \mathbf{x}^{(*)}(n - n_0)e^{j2\pi\alpha n}, \tag{5}$$

where $\mathbf{c}$ denotes a control vector which is used as the beamforming vector for $\mathbf{u}(n)$. The objective function of the cross-SCORE algorithm is the cross-correlation between the beamforming output $y(n) = \mathbf{w}^{\mathrm{H}}\mathbf{x}(n)$ and the reference signal $r(n)$. The objective function becomes a generalized Rayleigh quotient for an optimal control vector and it can be represented as [6],

$$\mathrm{J}_{CS}(\mathbf{w}; \mathbf{c}_{opt}) = \frac{\mathbf{w}^{\mathrm{H}}[\mathbf{R}_{\mathbf{xu}}\mathbf{R}_{\mathbf{uu}}^{-1}\mathbf{R}_{\mathbf{ux}}]\mathbf{w}}{\mathbf{w}^{\mathrm{H}}\mathbf{R}_{\mathbf{xx}}\mathbf{w}}. \tag{6}$$

The beamforming vector $\mathbf{w}(n)$ and the control vector $\mathbf{c}(n)$ maximizing the above objective function can be calculated by solving the joint-eigenvalue problem expressed by (7) and (8),

$$\lambda\mathbf{R}_{\mathbf{xx}}\mathbf{w} = [\mathbf{R}_{\mathbf{xu}}\mathbf{R}_{\mathbf{uu}}^{-1}\mathbf{R}_{\mathbf{ux}}]\mathbf{w}, \tag{7}$$

$$\lambda\mathbf{R}_{\mathbf{uu}}\mathbf{c} = [\mathbf{R}_{\mathbf{ux}}\mathbf{R}_{\mathbf{xx}}^{-1}\mathbf{R}_{\mathbf{xu}}]\mathbf{c}. \tag{8}$$

Eigenvectors of (7) and (8) corresponding to the maximum eigenvalue of the joint-eigenvalue problem become $\mathbf{w}(n)$ and $\mathbf{c}(n)$. The update process of $\mathbf{w}(n)$ and $\mathbf{c}(n)$ can be represented as follows:

$$\mathbf{w}_{\mathrm{CS}}(n) = \widehat{\mathbf{R}}_{\mathbf{xx}}^{-1}\widehat{\mathbf{R}}_{\mathbf{xu}}\mathbf{c}(n-1), \tag{9}$$

$$\mathbf{w}_{\mathrm{CS}}(n) = \frac{\mathbf{w}(n)}{\|\mathbf{w}(n)\|}, \tag{10}$$

$$\mathbf{c}(n) = \widehat{\mathbf{R}}_{\mathbf{uu}}^{-1}\widehat{\mathbf{R}}_{\mathbf{ux}}\mathbf{w}(n), \tag{11}$$

where normalization process (11) is an essential to limit the magnitude of $\mathbf{w}(n)$ and $\mathbf{c}(n)$, and each correlation matrix has relations $\widehat{\mathbf{R}}_{\mathbf{xu}}^{\mathrm{H}} = \widehat{\mathbf{R}}_{\mathbf{ux}}$, $\widehat{\mathbf{R}}_{\mathbf{uu}} = \widehat{\mathbf{R}}_{\mathbf{xx}}^{(*)}$, $\widehat{\mathbf{R}}_{\mathbf{uu}}^{-1} = [\widehat{\mathbf{R}}_{\mathbf{xx}}^{-1}]^{(*)}$. These relationships can be used to reduce the computational complexity.

III. The Proposed Method

In the presence of multiple SOIs, we consider the multi-target (MT)-SCORE algorithm to obtain each desired signal separately. Basically, the proposed algorithm can extract multiple SOIs by constructing the SCORE algorithm with different cyclic-frequencies in parallel. Also, to ensure convergence of each SCORE algorithm, the DMP algorithm is used together to estimate and to allocate initial beamforming vectors.

A. Dominant mode prediction (DMP) algorithm

The initial beamforming vector $\mathbf{w}_{initial}$ extracting the new signal can be obtained by the DMP algorithm, $\mathbf{w}_{initial}$ is orthogonal to the signal subspace included in the covariance matrix $\mathbf{R}_{\mathbf{xx}}(j-1)$ of the previous block. Because of this characteristic, the initial beamforming vector assigned to the new port can acquire a new signal while eliminating the existing signal. The initial beamforming vector is the eigenvector corresponding to the maximum eigenvalue of the generalized eigenvalue problem as follows:

$$\mathbf{R}_{\mathbf{xx}}(j)\mathbf{w}_{initial} = \lambda\mathbf{R}_{\mathbf{xx}}(j-1)\mathbf{w}_{initial}. \tag{12}$$

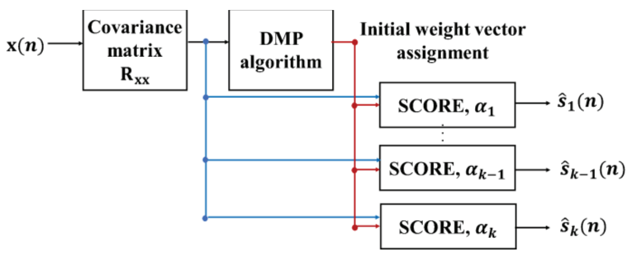

Fig. 1. The block diagram of the proposed algorithm

B. *Multi-target (MT)-SCORE algorithm with DMP*

In environments where multiple signal sources appear, the proposed MT-SCORE algorithm can be considered to obtain each signal individually. The proposed algorithm consists of DMP algorithm and multiple SCORE algorithms with different cyclic-frequencies of SOIs. In order to converge to the different SOIs in each SCORE algorithm when a new signal appears, the DMP algorithm estimates and allocates appropriate initial beamforming vectors to each SCORE algorithm. The block diagram of the proposed algorithm is represented as in Fig. 1.

IV. SIMULATION

In this section, simulations were performed to compare the beamforming performance with the proposed algorithm and the conventional cross-SCORE algorithm. Simulation results show the maximum eigenvalues and initial beamforming vector obtained by DMP algorithm, and the beamforming gain with respect to the incidence direction of the SOI and the interference. Specific simulation parameters are summarized in Table 1.

When signal 2 is newly emerging in 0.002 second, it can be seen that the maximum eigenvalue suddenly increases as shown in Fig. 2. An eigenvector corresponding to the suddenly increased eigenvalue is assigned to the initial beamforming vector to the cross-SCORE algorithm of the second beamformer port. The beampattern of initial beamforming vector is shown as in Fig. 3 by a solid line. The dotted line represents the beamforming vector of the conventional cross-SCORE algorithm.

TABLE I. SIMULATION PARAMETERS

Parameters	Values or variables	
	Signal 1 (interference)	***Signal 2 (SOI)***
Modulation type	Binary phase shift keying (BPSK)	
Sampling rate f_s	9 MHz	
# of samples per symbol f_s/f_{bd}	10	9
Cyclic-frequency α	90 kHz	100 kHz
Direction of arrival (DoA)	20°	50°
# of sensor elements M	10	
Observation time	0.01 second	
Appearance time	0 second	0.002 second
Signal to noise ratio (SNR)	20 dB	
Pulse shaping filter	Squared root raised cosine (SRRC) filter	
Filter roll-off factor	1	
Filter bandwidth	100 kHz	
Reference signal delay sample	0	

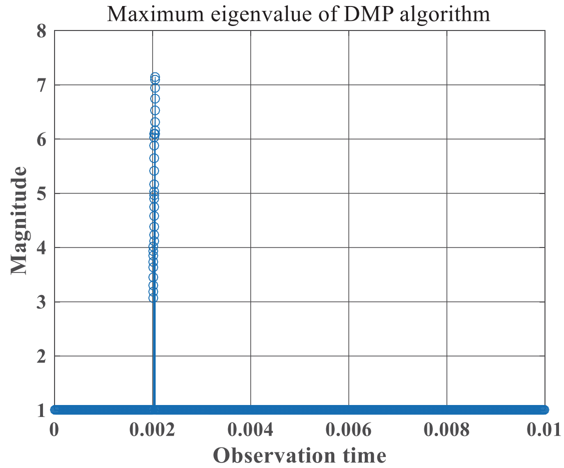

Fig. 2. The maximum eigenvalue plot of DMP algorithm

In the conventional cross-SCORE algorithm, the beamforming vector has gain difference about 14 dB between the SOI and the interference. The proposed algorithm shows about 30 dB gain difference and has better performance to eliminate interference than the conventional cross-SCORE algorithm.

When the SOI appears at 0.02 seconds, Fig. 4 represent the beamforming gain of second beamformer port with respect to the incidence direction of the SOI and the interference. In the second beamformer port to extract the SOI, the beamforming gain for the direction of the interference is low. In terms of beamforming gain for the SOI direction, the proposed algorithm converges about 50 samples and the conventional cross-SCORE takes about 200 samples after the emergence of SOI. The results confirm that the proposed algorithm shows better performance than the conventional cross-SCORE.

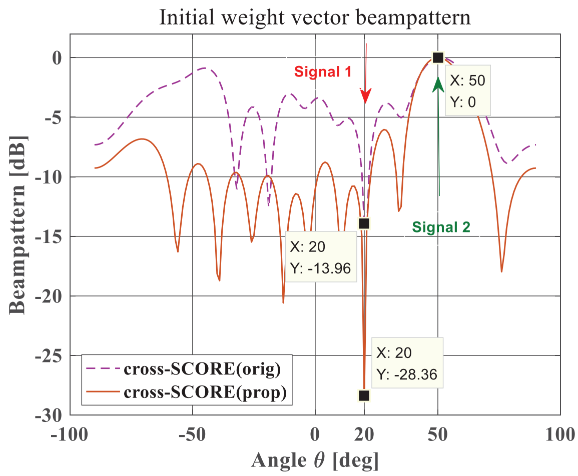

Fig. 3. The weight vector beampattern of cross-SCORE algorithms.

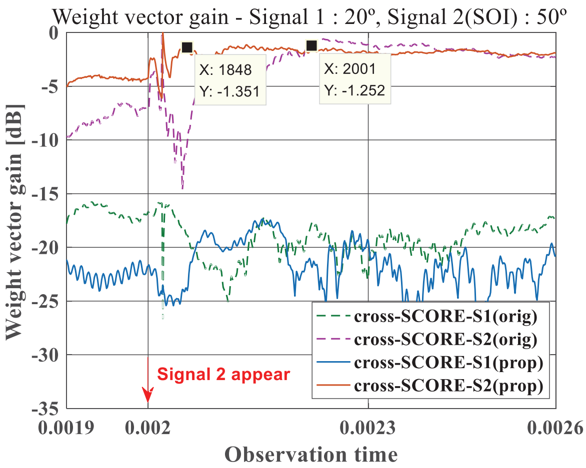

Fig. 4. The weight vector gain of cross-SCORE algorithms.

V. Conclusion

We proposed an MT-SCORE algorithm incorporating the DMP algorithm in time-varying environments. Simulation results show that the proposed scheme has faster convergence than the conventional cross-SCORE algorithm. Adoption of the DMP algorithm makes the proposed algorithm obtain an efficient initial beamforming vector and leads to the reliable removal of existing interference. However, the DMP algorithm requires more computational complexity because of eigenvalues and eigenvectors. The complexity reduction will be studied in the future works.

References

[1] B. G. Agee, "The property restoral approach to blind adaptive signal extraction," Ph.D. dissertation, Dept. of Electrical Engineering and Computer Science, Univ. of California, Davis, CA, 1989.

[2] B. G. Agee, S. V. Schell, W. A. Gardner, "Spectral Self-coherence Restoral A New Approach to Blind Adaptive Signal Extraction Using Antenna Arrays," in Proc. IEEE 1990, VOL. 78, NO. 4, pp. 753-767, 1990.

[3] Kehu Yang, "Super-Exponential Blind Adaptive Beamforming," IEEE Transactions on Signal Processing, vol. 52, Issue. 6, June 2004.

[4] W. A. Gardner, A. Napolitano, and P. Paura, "Cyclostationarity: Half a century of research," Signal Processing, vol. 86, no. 4, pp. 639 – 697, April 2006.

[5] Wei Zhang, Wei Liu, "Low-Complexity Blind Beamforming Based On Cyclostationarity," 20th European Signal Processing Conference (EUSIPCO 2012), pp. 1-5, Aug. 2012.

[6] K. L. Du, M. N. S. Swamy, "A Class of Adaptive Cyclostationary Beamforming Algorithms," Circuits Syst Signal Process (2008), vol. 27, pp. 35-63, 2008.

[7] B. G. Agee, "Fast Acquisition of Burst and Transient Signals Using a Predictive Adaptive Beamformer," in Proc. 1989 IEEE Military Communications Conference, 1989.