Blind Source Separation for Multi-carrier Efficient Modulations Using MIMO Antennas

Zhimin Chen[1], Jingchao Li[1], Peng Chen[2(✉)], and Pu Miao[3]

[1] Shanghai Dianji University, Shanghai 201306, China
[2] Southeast University, Nanjing 210096, China
chenpengdsp@seu.edu.cn
[3] Qingdao University, Qingdao 266071, China

Abstract. In this paper, the blind source separation (BSS) problem in the multi-carrier efficient communication system is considered, and a novel joint approximative diagonalization of eigenmatrix (JADE)-based multiple-input and multiple output (MIMO) model is proposed to separate the mixed signal that the antennas received. Then, the special impacting filter (SIF)-based demodulation method is adopted to demodulate the separated signals. Additionally, different from the traditionally efficient demodulation method, the proposed method can achieve higher communication capacity and spectrum utilization by combining the MIMO technology and JADE-based separation algorithm. Simulation results show that the JADE-based MIMO efficient communication system can separate the mixed signals efficiently, reduce the symbol interference and significantly improved the system performance by using the multiple antennas.

Keywords: Blind source separation · Efficient modulation · JADE MIMO

1 Introduction

The efficient modulation, which has good flexibility, univerality and anti-jamming characteristics, was first proposed by Wu [1,2]. Unlike the ultra wide band communication, the efficient modulated signal is sine-like, the symbol "0" is modulated by N sine carrier cycles and the non-zeros has phase change during the K ($K \ll N$) carrier cycles in the N carrier cycles, the waveform of the modulated signal is shown in Fig. 1. As the sine has a impulse sharp in the frequency domain, the sine-like efficient modulated signal has the similar characteristics, which can achieve high band efficiency and high-speed data transmission within quite narrow bandwidth [3,4]. Up until now, various efficient modulation methods have been proposed, such as the variable phase shifting keying (VPSK), enhanced VPSK, very minimum shifting keying (VMSK), pulse position phase reversal keying (3PRK), missing cycle modulation (MCM), suppressed cycle modulation (SCM), and minimum sideband modulation (MSB), etc. [5–9]. The above modulations have a same characteristic, that is "asymmetric".

G. Sun and S. Liu (Eds.): ADHIP 2017, LNICST 219, pp. 546–554, 2018.
https://doi.org/10.1007/978-3-319-73317-3_64

The demodulation of the efficient signal is based on the special digital impacting filter (SIF) [10–13]. The SIF is a kind of digital IIR filter that has one pair of zeros and multiple pair of poles, the frequency response of the SIF was shown in Fig. 2. When the SIF works on the proper frequency, it can convert the phase change to amplitude impacting and remove the most noises at the same time. As the output signal reveal obvious amplitude different, we can use simple threshold detection method to demodulate the signals in the intermediate frequency, which can avoid down-conversion to baseband to demodulate the signals. However, the SIF can not demodulate the non-orthogonal multi-carrier signals. [14] proposed a blind source separation method to separate the mixed signals, which can assistant the demodulation and achieve significant effect. Since the multiple-input and multiple-output (MIMO) can provied more spatial diversity, combine the MIMO and the BSS algorithm to separate the mixed carriers may be an feasible solution [15–18]. As the multi-carrier efficient system is non-orthogonal, we can use the SIMO scheme to decrease the symbol interference. In this paper, we first give the system model of the SIMO multi-carrier system. Then, we propose two BSS algorithms, one is based on the Kalman filtering (KF), the other one is the joint approximative diagonalization of eigenmatrix (JADE) algorithm. Finally, we give the simulation results and conclude the paper.

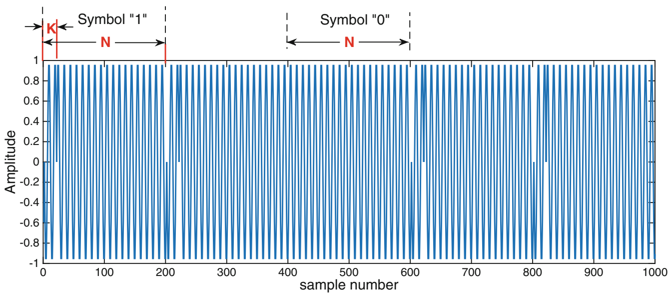

Fig. 1. Waveform of the efficient modulation signal

The organization of this manuscript is as follows. In Sect. 2, the system model of the MIMO efficient communication with interference is described. Next, in Sect. 3, the blind source separation algorithm and Kalman filtering method is proposed to demodulate the mixed signals. Section 4 gives the simulation results. Finally, Sect. 5 concludes the paper.

The notations used in this work are defined as follows. Symbols for vectors (lower case) and matrices (upper case) are in bold face. $\boldsymbol{I}_N$, $\mathcal{N}\left(0, \sigma_n^2 I\right)$, $(\cdot)^T$, $(\cdot)^H$, $\operatorname{diag}\{\cdot\}$, $*$ and $\lfloor\cdot\rfloor$ denote the $N \times N$ identity matrices, the Gaussian distribution with zero mean and covariance being $\sigma_n^2 I$, the transpose, the conjugate transpose (Hermitian), the diagonal matrix, the convolution and the floor function, respectively.

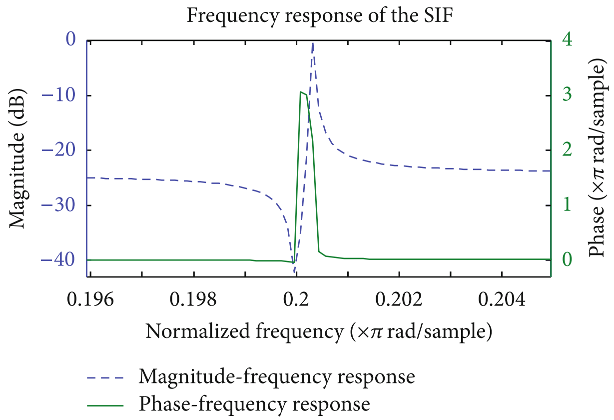

Fig. 2. Frequency response of the special impacting filter

2 System Model of the SIMO Communication with Interference

The SIMO communication system considered in this section is shown in Fig. 3, where the communication system has one transmit antenna and multi receive antennas, and the receive signal is interfered with the independent signal. The number of the receive antennas is Q. The transmitted signal can be expressed as

$$\mathbf{s} = \mathbf{s}_1 + \mathbf{s}_2 + \ldots + \mathbf{s}_P, \tag{1}$$

where $\mathbf{s}_p \in \mathbb{R}^{L\times 1}$ denotes the efficient signal with the carrier frequency being f_p, and L denotes the length of the sampling signal. The receive signal $\mathbf{y}_q \in \mathbb{R}^{L\times 1}$ at the qth antenna is

$$\mathbf{y}_q = a_q\mathbf{s} + b_q\mathbf{s}_I + \mathbf{n}_q, \tag{2}$$

where a_p denotes the channel attenuation between the transmitter and the qth receive antenna, b_p denotes the channel attenuation between the interference and the qth receive antenna, $\mathbf{s}_I$ denotes the interference signal and $\mathbf{n}_q$ denotes the additive white Gaussian noise (AWGN). Then we can obtain the matrix of the receive signal

$$\mathbf{Y} = \mathbf{a}\mathbf{s}^T + \mathbf{b}\mathbf{s}_I^T + \mathbf{N}, \tag{3}$$

where

$$\mathbf{Y} \triangleq \left(\mathbf{y}_1, \mathbf{y}_2, \ldots, \mathbf{y}_Q\right)^T. \tag{4}$$

3 Demodulation of the Efficient Modulation Signals

In this work, we propose two approaches to demodulate the multi-carrier signal with the interference, one is based on the Kalman filtering (KF) [19], the other one is based on the joint approximative diagonalization of eigenmatrix (JADE) algorithm, and each approach has two steps:

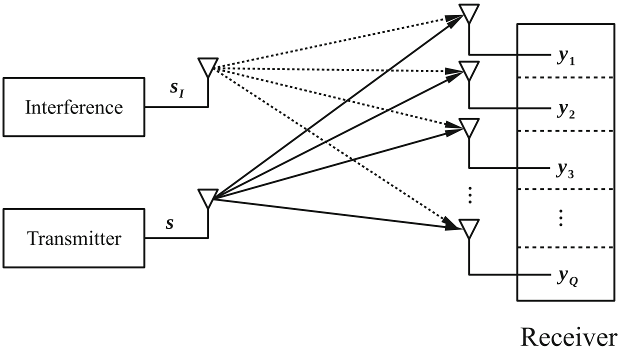

Fig. 3. The system model of the SIMO communication with interference

1. Separate the multi-carrier signal from the interfered receive signal based on the blind source separation (BSS);
2. The demodulation of the multi-carrier signal by the SIF.

The lth column of the receive signal $\mathbf{Y}$ denotes as $\mathbf{y}_l \in \mathbb{R}^{Q\times 1}$, and

$$\mathbf{y}_l = \mathbf{A}\mathbf{x}_l + \mathbf{n}_l, \tag{5}$$

where $\mathbf{A} \triangleq \left(\mathbf{a}, \mathbf{b}\right)$, $\mathbf{x}_l \triangleq \begin{pmatrix} s_l \\ s_{I,l} \end{pmatrix}$, $\mathbf{n}_l$ denotes the noise, s_l and $s_{I,l}$ respectively denote the lth entry of the transmit signal $\mathbf{s}$ and interference signal. During the process of the BSS, the separating matrix $\mathbf{B}_l \in \mathbb{R}^{2\times Q}$ is adopted to separate the mixture signal $\mathbf{y}_l$, and we can obtain the separated signal $\mathbf{z}_l \in \mathbb{R}^{2\times 1}$

$$\mathbf{z}_l = \mathbf{B}_l\mathbf{y}_l. \tag{6}$$

In the theory of the BSS, the separating matrix $\mathbf{B}_l$ includes two parts, i.e., the prewhitening matrix $\mathbf{U}_l \in \mathbb{R}^{2\times Q}$ and the weight matrix $\mathbf{W}_l \in \mathbb{R}^{2\times 2}$, and

$$\mathbf{B}_l = \mathbf{W}_l^T\mathbf{U}_l. \tag{7}$$

3.1 The Separation of the Multi-carrier Signal Based on the BSS via the KF Algorithm

We first attain $\mathbf{v}_l \triangleq \mathbf{U}_l\mathbf{y}_l$ by the prewhitening matrix $\mathbf{U}_l$, where $\mathbf{v}$ is the normalized white vector with the zero mean and unity covariance $\mathcal{E}\left\{\mathbf{v}_l\mathbf{v}_l^T\right\} = I$. The LMS-type prewhitening matrix is adopted

$$\mathbf{U}_l = \mathbf{U}_{l-1} + \lambda_l\left[I - \left(\mathbf{U}_{l-1}\mathbf{y}^l\right)\left(\mathbf{U}_{l-1}\mathbf{y}^l\right)^T\right]\mathbf{U}_{l-1}, \tag{8}$$

where λ_l is a leaning rate.

During the process of obtaining the weight matrix $\mathbf{W}_l$, the KF method is adopted [20]

$$\mathbf{d}_l = g(\mathbf{W}_{l-1}^T \mathbf{v}_l) \tag{9}$$

$$\mathbf{h}_l = \mathbf{K}_{l,l-1} \mathbf{d}_l \tag{10}$$

$$\mathbf{m}_l = \mathbf{h}_l / \left(\mathbf{d}_l^T \mathbf{h}_l + Q_l \right) \tag{11}$$

$$\mathbf{K}_{l+1,l} = \mathbf{K}_{l,l-1} - \mathbf{m}_l \mathbf{h}_l^T \tag{12}$$

$$\mathbf{W}_l^T = \mathbf{W}_{l-1}^T + \mathbf{m}_l \left(\mathbf{v}_l^T - \mathbf{d}_l^T \mathbf{W}_{l-1}^T \right), \tag{13}$$

where $\mathbf{K}_{l,l-1} = \mathcal{E}\left\{ \left(\mathbf{W}_l^T - \hat{\mathbf{W}}_l^T \right) \left(\mathbf{W}_l^T - \hat{\mathbf{W}}_l^T \right)^T \right\}$, $Q_l = \|\mathbf{v}_l - \mathbf{W}_{l-1} \mathbf{d}_l\|_2^2$ and $g(t) = t - \tanh(t)$.

3.2 The Separation of the Efficient Signal from the Interfered Receive Signal Based on the BSS via the JADE Algorithm

The separation of the multi-carrier signal from the interfered receive signal based on the BSS via the JADE algorithm is described in Algorithm 1. Statistical performance is achieved by involving all the cumulants of order 2 and 4 while a fast optimization is obtained by the device of joint diagonalization [21,22].

4 Simulation Results

First, we evaluate the proposed methods of the multi-carrier efficient signal demodulation, and the simulation parameters are given in Table 1. To show the simulation results more clearly, we set 4 sub-carrier and use the M-ary efficient signal as the sources. Additionally, these parameters are the same for the simulations in the following contents, if there is no additional statement.

Table 1. Simulation parameters

Parameter	Value
The M-ary efficient signal	$M = 2$
Carrier frequencies	$10e^6 10.005e^6 10.002e^6 10.001e^6$
Sample frequency	$10 \times 10e^6$
Symbol length N	$N = 100$
Phase change length K	$K = 2$
Transmit antennas	1
Received antennas	4

In the proposed methods of the signal demodulation, two steps are included, where at the first step the mixed signal is separated and at the second step a

Algorithm 1. The BSS based on the JADE

1: Calculate the prewhitening matrix $\mathbf{U}$ from the covariance matrix $\mathbf{R}_y$ of the receive signal, and the prewhitening matrix should satisfy the follow condition

$$\mathbf{UA} = \mathbf{V}, \tag{14}$$

where $\mathbf{V}$ is an unitary matrix. Then we can obtain the prewhitening matrix $\mathbf{U}$ from the subspace decomposition of $\mathbf{R}_y$

$$\mathbf{U} = \left[\left(\lambda_1 - \sigma_n^2\right)^{-\frac{1}{2}} \mathbf{g}_1, \left(\lambda_2 - \sigma_n^2\right)^{-\frac{1}{2}} \mathbf{g}_2 \right]^H, \tag{15}$$

where λ_1, λ_2 are the two maximal eigenvalues of $\mathbf{R}_y$, $\mathbf{g}_1$ and $\mathbf{g}_2$ are the corresponding eigenvector. σ_n^2 is the variance of noise, which is the mean value of the left eigenvalues.

2: Obtain the whiten signal $\mathbf{v}_l$

$$\begin{aligned} \mathbf{v}_l &= \mathbf{U}\mathbf{y}_l = \mathbf{U}\left(\mathbf{A}\mathbf{x}_l + \mathbf{n}_l\right) \\ &= \mathbf{V}\mathbf{x}_l + \mathbf{U}\mathbf{n}_l. \end{aligned} \tag{16}$$

3: The matrix of the fourth-order cumulant of the whiten signal is defined as

$$\left\{\mathbf{Q}\left(\mathbf{P}\right)\right\}_{ij} = \sum_{k,r=1}^{2} \operatorname{cum}\left\{v_i, v_j^H, v_k, v_r^H\right\} P_{rk}, \tag{17}$$

where P_{rk} denotes the rth and kth column of an arbitrary non-zeros matrix $\mathbf{P} \in \mathbb{R}^{2\times 2}$, and $\left\{\mathbf{Q}\left(\mathbf{P}\right)\right\}_{ij}$ denotes the ith and jth column of the fourth-order cumulant $\mathbf{Q}\left(\mathbf{P}\right)$. The fourth-order cumulant can be expressed as

$$\begin{aligned} &\operatorname{cum}\left\{v_i, v_j^H, v_k, v_r^H\right\} = \mu_4\left\{v_i, v_j^H, v_k, v_r^H\right\} \\ &- \mu_2\left\{v_i, v_j^H\right\}\mu_2\left\{v_k, v_r^H\right\} - \mu_2\left\{v_i, v_k\right\}\mu_2\left\{v_j^H, v_r^H\right\} \\ &- \mu_2\left\{v_i, v_r^H\right\}\mu_2\left\{v_j^H, v_k\right\}, \end{aligned} \tag{18}$$

where $\mu_4\left\{v_i, v_j^H, v_k, v_r^H\right\} = \frac{1}{L}\sum_{l=1}^{L} v_{l,i}v_{l,j}^H v_{l,k}^H v_{l,r}$, $\mu_2\left\{v_i, v_j^H\right\} = \frac{1}{L}\sum_{l=1}^{L} v_{l,i}v_{l,j}$, $\mu_2\left\{v_k, v_r^H\right\} = \frac{1}{L}\sum_{l=1}^{L} v_{l,k}v_{l,r}$, $\mu_2\left\{v_i, v_k\right\} = \frac{1}{L}\sum_{l=1}^{L} v_{l,i}v_{l,k}^H$, $\mu_2\left\{v_j^H, v_r^H\right\} = \frac{1}{L}\sum_{l=1}^{L} v_{l,j}v_{l,r}$, $\mu_2\left\{v_i, v_r^H\right\} = \frac{1}{L}\sum_{l=1}^{L} v_{l,i}v_{l,r}$, $\mu_2\left\{v_j^H, v_k\right\} = \frac{1}{L}\sum_{l=1}^{L} v_{l,j}^H v_{l,k}^H$.

4: From the eigen decomposition of $\mathbf{Q}\left(\mathbf{P}\right)$, we can attain the approximation of $\mathbf{V}$

$$\mathbf{Q}\left(\mathbf{P}\right) = \hat{\mathbf{V}}\mathbf{\Sigma}\hat{\mathbf{V}}^H. \tag{19}$$

5: The separated signal is

$$\mathbf{z}_l = \hat{\mathbf{V}}^H\mathbf{U}\mathbf{y}_l. \tag{20}$$

SIF is adopt to filtering the signals. At the first step, the BSS for 4 carriers with interference in the SIMO scenario is shown in Fig. 4, in order to show the separation more clearly, Fig. 4 only give 2 sub-carrier's results, and we can see that the mixed signals with interference can be separated successfully.

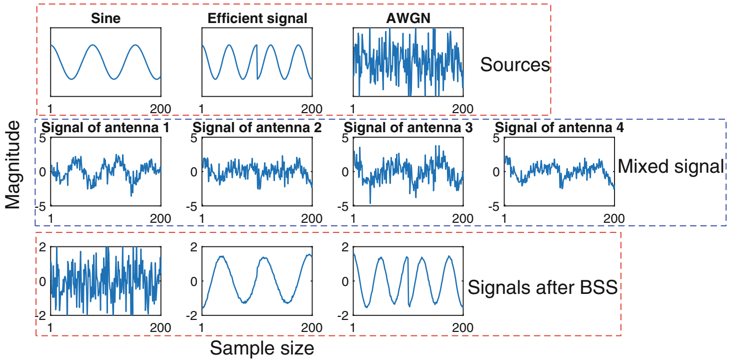

Fig. 4. The BSS separation process of the mixed signals

Additionally, the demodulation processes with the SIF are also shown in Fig. 5. As the demodulation results are sensitive with the first step, in the practical communication system, the number of the sub-carriers is constraint. For example, 4 signals are used in our simulation, and 20 signals are used in practice. Then, use the threshold determination to obtain the demodulator results. As shown in Fig. 5, we can see the final output signals can achieve better performance at the whole duration. Figure 6 shows the BER performance of the proposed system, from Fig. 6, we can see that the BER performance of each sub-carrier is affected by the carrier interval. Since we use one sample frequecy and the SIF must work in proper range, the performances of each sub-carrier is different, the best is the sub-carrier 1 and others decent orderatly. However, even the subcarrier 4, can still obtain satisfactory performance.

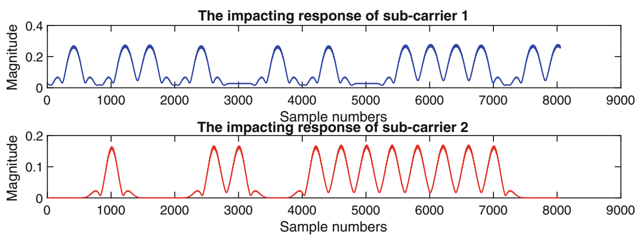

Fig. 5. The demodulation of the sub-carriers with the SIF

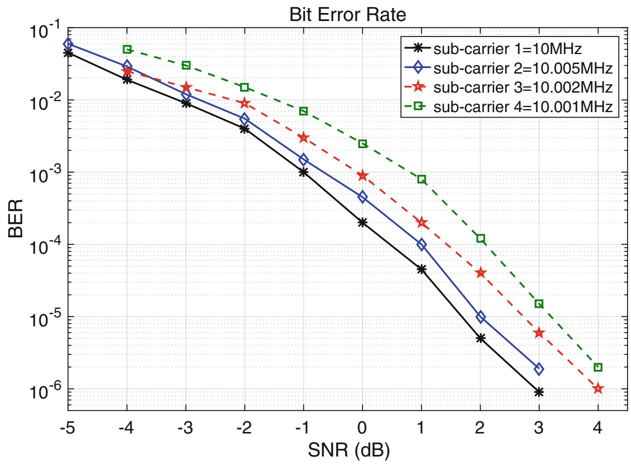

Fig. 6. BER performance of the system

5 Conclusions

In this work, the demodulation for multi-carrier signals has been considered. The system model has been established for the multi-carrier MIMO efficient system. Kalman filtering and JADE algorithms have been adopted to separate the mixed carriers and the inerferences. Moreover, a novel two-step method has been proposed to demodulate the subcarriers and to improve the demodulation performance. The simulation results show that the demodulation performance can be significantly improved by adopting the BSS and MIMO. Future work will concentrate on the waveform optimization for multiple transmit antennas in the multi-carrier efficient system.

Acknowledgment. This work was supported in part by the National Natural Science Foundation of China (Grant No. 61601281 and No. 61603239).

References

1. Wu, L.: UNB modulation in high speed space communications. In: Proceedings of the SPIE International Society Optical Engineering, Wuhan, vol. 6795(Part One), pp. 679510-1–679510-6, November 2007
2. Wu, L., Feng, M., Qi, C.: On BER performance of EBPSK-MODEM in AWGN channel. Sensors **10**(4), 3824–3834 (2010)
3. Wu, L., Feng, M.: Recent patents on ultra narrow band modulations. Recent Pat. Signal Process. **1**(1), 36–47 (2011)
4. He, F., Wu, L.: Analysis of power spectrum of continuous phase waveforms for binary modulation communications. In: Proceedings of the International Conference Ultra Modern Telecommunications and Workshops, St. Petersburg, Russia, pp. 1–5, October 2009

5. Feng, M., Wu, L.: Special non-linear filter and extension to Shannon's channel capacity. Digit. Signal Process. Rev. J. **19**(5), 861–873 (2009)
6. Jin, Y., Wu, L., Wang, J., Yu, J.: A new detector in EBPSK communication system. J. Southeast Univ. Engl. Ed. **27**(3), 244–247 (2011)
7. Feng, M.: Research on key problems in high-efficiency modulation. Ph.D. thesis, Southeast University (2008)
8. Chen, X.: Research on detection and channel coding of efficient modulation communication system. Ph.D. thesis, Southeast University (2013)
9. Zhang, P., Wu, L.: A realization method for multi-carrier MPPSK modulations. Progress in mechatronics and information technology. Appl. Mech./Mater. **462–463**, 615–618 (2013)
10. Feng, M., Wu, L., Gao, P.: An EBPSK demodulator based on ANN detection. In: International Conference on Informational Science and Engineering, ICISE-Proceedings, Hangzhou, China, pp. 969–972, December 2010
11. Feng, M., Wu, L., Gao, P.: From special analogous crystal filters to digital impacting filters. Digit. Signal Process. Rev. J. **22**(4), 690–696 (2012)
12. Ying, P., Wu, L.: New scheme of MPPSK modem. J. Southeast Univ. Engl. Ed. **42**(2), 204–208 (2012)
13. Zhu, R., Wu, L.: Nonlinear geometric feature equalizers based on minimum bit error rate criterion for EBPSK communications. In: Proceedings of the SPIE International Society Optical Engineering, Article no.: 67951D (2007)
14. Chen, Z., Wu, L.: Blind source separation of dual-carrier MPPSK signal based on smoothed pseudo wigner distribution. In: Proceedings of the 9th International Symposium on Communication Systems, Networks and Digital Signal, Manchester, UK, pp. 664–667, October 2014
15. Chen, Z., Wu, L., Chen, P.: Efficient modulation and demodulation methods for multi-carrier communication. IET Commun. **10**(5), 567–576 (2016)
16. Chen, Z., Wu, L.: Design of special impacting filter for multicarrier ABPSK system. Math. Probl. Eng. Article ID: 921932 (2013)
17. Chen, Z., Wu, L.: The dual carrier ABSK system based on a FIR bandpass filter. Sensors **14**(3), 5644–5653 (2014)
18. Chen, P., Qi, C., Wu, L., Wang, X.: Estimation of extended targets based on compressed sensing in cognitive radar system. IEEE Trans. Veh. Technol. **66**(2), 941–951 (2017)
19. Chen, P., Qi, C., Wu, L.: Antenna placement optimisation for compressed sensing-based distributed MIMO radar. IET Radar Sonar Navig. **2**(11), 285–293 (2017)
20. Mirzaei, F.M., Roumeliotis, S.I.: A Kalman filter-based algorithm for IMU-camera calibration: observability analysis and performance evaluation. IEEE Trans. Rob. **24**(5), 1143–1156 (2008)
21. Cardoso, J.F., Souloumiac, A.: Blind beamforming for non Gaussian signals. IEE-Proc.-F **140**(6), 362–370 (1993)
22. Cardoso, J.F.: High-order contrasts for independent component analysis. Neural Comput. **11**(1), 157 (1989)