Regular paper http://dx.doi.org/10.13067/JKIECS.2013.8.10.1451

2×2 지연 혼합에서의 암문신호처리를 위한 고유값분석을 통한 초기값 설정

박근수*

Initial Weighting Establishment Through Eigenanalysis for BSS in Two-by-two Delayed Mixture

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요 약

본 논문은 고유값분석을 이용하여 주파수영역 독립성분석(FDICA)의 수렴속도를 증가시키기 위한 기법을 제안한다. 소나 시스템 등에서는 지연정보를 획득하여 간섭신호원을 빠른 속도로 제거하는 알고리즘이 중요하다. 두 개의 독립신호가 2×2 지연 혼합된 경우에 대한 고유값 분석을 통하여, 초기값 파라미터로 사용할 지연정보를 획득할 수 있다. 본 알고리즘을 검증하기 위한 컴퓨터 시뮬레이션은 수렴속도와 잡음제거에서의 성능향상을 보여준다. 초기조건이 목표값에 근접하고 있기 때문에 3회 정도의 반복수렴 실험으로도 잡음제거에 상당한 성능을 나타낸다. 수렴 후에도 기존 알고리즘보다 1~3dB 더 나은 잡음제거 성능을 볼 수 있다.

ABSTRACT

This paper propose a method for fast convergence technique in frequency domain independent component analysis (FDICA) using eigenanalysis. It important ,such as SONAR system, to eliminate the interference sources through fast algorithm. Through eigenanalysing a two-by-two delayed mixture case, information of delay can be used for initial weighting parameters. Simulations show the improved performances in convergence speed and noise rejection rate. The proposed method can present close weights for optimal convergence, noise can be diminished drastically about 3 times epoch, and get the better resultss with 1~3dB than the conventional method.

키워드

BSS, FDICA, Eigenanalysis, Initial Weight Condition
암묵신호처리, 주파수영역 독립성분분석, 고유값분석, 초기값 조건

Ⅰ. Introduction

Separating a noise from the mixture of signal sources is important issue in signal processing [1][2]. It is called a various terms as criterion, one of the techniques for separating an original signal in mixed signals is called blind source separation (BSS). An independent component analysis(ICA) is one technical method for BSS. ICA uses attribute of the independent signal source having a

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접수일자 : 2013. 08. 22 심사(수정)일자 : 2013. 09. 23 게재확정일자 : 2013. 10. 23

non-gaussian distribution. After maximizing the non-gaussian distribution performance, the independent sources are extracted from mixture.

But ICA method inherently has a significant disadvantage which is due to low convergence through nonlinear optimization. In study [3], a new algorithm based on the temporal alternation of learning between ICA and beamforming is proposed. The matrix based on null substitute the initial matrix of the unmixing matrix for acceleration of the iterative optimization. However, beamforming technique needs the parameter of direction of arrival (DOA) and has a burden of calculation.

Additionally, frequency domain independent component analysis (FDICA) learning algorithm requires an ‘epoch’ which means repeats of the observed signal to reach to the enough separation [4]. It means that the signal data should be stocked in memory to process the ICA. Although the natural gradient algorithm is quite efficient and does not involve the matrix inverse, it still requires intensive computation.

When the gradient decent class algorithm is used, it tends to converge to the local minimum of the objective functions closest to the initial conclusions. How initial weight affects generalization performance and efficiency is largely determined by the dynamics of the training algorithm [5].

In this paper, an initial weight establishment for FDICA of two-by-two delayed mixture is proposed in order to improve convergence speed and separation performance. In the case of delayed mixture, the delay information can be obtained from eigenvector polynomials by eigenanalysis of the correlation matrix of the observed signals. Eigenalaysis methods are applied to various fields [6]. With little modification of the obtained eigenvectors, we can use them as the initial weights of the learning network. When the eigenvectors are calculated, there are no additional calculations because it is in the processing of whitening. The eigenvectors are used as initial weighting and overcome the disadvantage of ‘epoch’ in FDICA algorithm.

The simulation results show the proposed method can improve the separation performance in SIR in a steadier state than that of conventional FDICA. Especially in early adaptation with just once or twice epochs, the proposed method has a drastic improvement in convergence performance.

Ⅱ. Problem Formulation

We consider the BSS with the case of two-by-two delayed mixture, which has its mixing matrix $\mathbf{A}$,

$$\mathbf{A} = \begin{bmatrix} a & bz^{-\delta_1} \\ cz^{-\delta_2} & d \end{bmatrix}, \left(\text{if } ad - bc \neq 0\right) \tag{1}$$

where $(\delta_1 \neq \delta_2)$

where a, b, c and d denote arbitrary mixing coefficients, and $(z^{-\delta_1}, z^{-\delta_2})$ are delay terms. To observe an optimal separating matrix, the ideal inverse matrix is investigated. The ideal inverse matrix of $\mathbf{A}$ can be obtained as (2)

$$\mathbf{W}^o \approx \mathbf{A}^{-1} = \begin{bmatrix} a & bz^{-\delta_1} \\ cz^{-\delta_2} & d \end{bmatrix}^{-1} = \frac{1}{ad - bcz^{-(\delta_1+\delta_2)}} \begin{bmatrix} d & -bz^{-\delta_1} \\ -cz^{-\delta_2} & a \end{bmatrix} = \begin{bmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \end{bmatrix},$$

where

$$\begin{aligned} w_{11} &= d_1 + d_2 z^{-(\delta_1+\delta_2)} + d_3 z^{-2(\delta_1+\delta_2)} + \cdots \\ w_{12} &= b_1 z^{-\delta_1} + b_2 z^{-\delta_1} z^{-(\delta_1+\delta_2)} + b_3 z^{-\delta_1} z^{-2(\delta_1+\delta_2)} \cdots \\ w_{21} &= c_1 z^{-\delta_2} + c_2 z^{-\delta_2} z^{-(\delta_1+\delta_2)} + c_3 z^{-\delta_2} z^{-2(\delta_1+\delta_2)} \cdots \\ w_{22} &= a_1 + a_2 z^{-(\delta_1+\delta_2)} + a_3 z^{-2(\delta_1+\delta_2)} + \cdots . \end{aligned} \tag{2}$$

Where $\mathbf{W}^o$ means the optimal solution for $\mathbf{A}$. It can be observed that the first delay $(z^{-\delta_1}, z^{-\delta_2})$ at each cross-channel exist in un-mixing system. For a conventional ICA, the initial weight is usually established as identity form initial weight in case of two-by-two like as Eq.(3).

$$W_o(f) = \begin{bmatrix} 1\ 1 \cdots 1 & 0 0 \cdots 0 \\ 0 0 \cdots 0 & 1\ 1 \cdots 1 \end{bmatrix} \quad (3)$$

III. Eigen-decomposition Analysis of Delayed Mixture

For eigenanalysis of the correlation matrix of delayed mixture in Eq. (1), we can express the correlation matrix $\mathbf{R}$ as following,

$$\mathbf{R} = \mathbf{A}\mathbf{A}^H = \begin{bmatrix} a^2+b^2 & acz^{+\delta_2}+bdz^{-\delta_1} \\ acz^{+\delta_1}+bdz^{-\delta_2} & c^2+d^2 \end{bmatrix}$$
$$= \begin{bmatrix} A & Bz^{+\delta_2}+Cz^{-\delta_1} \\ Bz^{-\delta_2}+Cz^{+\delta_1} & D \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{bmatrix},$$
$$\text{where, } A = a^2+b^2, B = ac, C = bd, \text{and } D = c^2+d^2. \quad (4)$$

where r_{11} and r_{22} are direct-channel components, r_{12} and r_{21} are cross-channel components. After the eigen-analysis, two eigenvalues, λ_1 and λ_2, of $\mathbf{R}$ are obtained.

$$\lambda = \frac{(A+D) \pm \sqrt{(A+D)^2 - 4K}}{2}$$
$$= \frac{A+D}{2} \pm \frac{1}{2}\sqrt{(A-D)^2 + 4[(B-C)^2 + BC(z^{\delta/2}+z^{-\delta/2})^2]},$$
$$\text{where } \delta = \delta_1 + \delta_2.$$
$$\text{Let } z = e^{j\omega}, z^{\delta/2}+z^{-\delta/2} = e^{j\omega\delta/2}+e^{-j\omega\delta/2} = \cos(\omega\delta/2). \quad (5)$$

We should confirm the condition of two eigenvalues to become real-number. Eq. (7) shows the confirmation of the positive semi-definite condition.

$$\lambda_1 = \frac{A+D}{2} + \frac{1}{2}\sqrt{(A-D)^2 + 4[(B-C)^2 + BC(z^{\delta/2}+z^{-\delta/2})^2]}.$$
$$\lambda_2 = \frac{A+D}{2} - \frac{1}{2}\sqrt{(A-D)^2 + 4[(B-C)^2 + BC(z^{\delta/2}+z^{-\delta/2})^2]}. \quad (6)$$

$$(B-C)^2 + BC(z^{\delta/2}+z^{-\delta/2})^2 = (B-C)^2 + BC\cos^2(\omega\delta/2) \geq 0. \quad (7)$$

Eigenvector for eigenvalue is obtained as the following:

$$\begin{bmatrix} A & Bz^{+\delta_2}+Cz^{-\delta_1} \\ Bz^{-\delta_2}+Cz^{+\delta_1} & D \end{bmatrix} \begin{bmatrix} e_1 \\ 1 \end{bmatrix} = \lambda_1 \begin{bmatrix} e_1 \\ 1 \end{bmatrix},$$
$$\mathbf{v}_1 = \begin{bmatrix} e_1 \\ 1 \end{bmatrix} \text{ for } \lambda_1$$
$$\text{, where } e_1 = \frac{Bz^{+\delta_2}+Cz^{-\delta_1}}{\lambda_1 - A}. \quad (8)$$

As the same routine, another eigenvector is obtained,

$$\mathbf{v}_2 = \begin{bmatrix} 1 \\ e_2 \end{bmatrix} \text{ for } \lambda_1.$$
$$\text{, where } e_2 = \frac{Bz^{-\delta_2}+Cz^{+\delta_1}}{\lambda_2 - D}. \quad (9)$$

Since both the eigenvalues are real number, we can obtain the delay information $(z^{-\delta_1}, z^{-\delta_2})$ from two cross-channel components respectively.

VI. Verification with Computer Simulation

In this paper, to perform the eigenanalysis processing, we use FIR polynomial matrix algebra [4]. Two element array sensor and two sentences spoken by two speakers (male, female) with 8 KHz sampling rate are used for simulation. In the range of (-1024, 1023), the FIR polynomial matrix algebra is processed for eigendecomposition.

Fig. 1 shows the corresponding eigenvector polynomials for mixture matrix Eq. (10).

$$\mathbf{A}_1 = \begin{bmatrix} 2 & z^{-2} \\ z^{-3} & 1 \end{bmatrix} \tag{10}$$

The delay information (z^{-2}, z^{-3}) is shown at off diagonal components (b),(c). The residual error around the peaks is due to the approximation error.

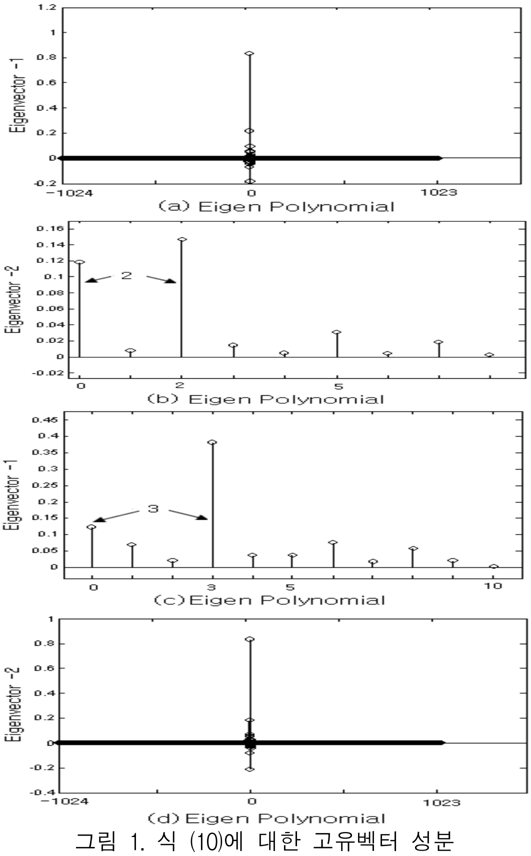

그림 1. 식 (10)에 대한 고유벡터 성분
Fig. 1 Eigenvector polynomials of Eq. (10)
(a)(c) : Eigenvectors of delay z^{-3}
(b)(d) : Eigenvectors of delay z^{-2}

In order to use the eigenvectors as the initial weights, the direct-channel components (Fig. 1 (a) and (d)) are modified by eliminating the non-causal parts. The cross-channel components (Fig. 1 (b) and (c)) are also modified by eliminating the non-causal parts and setting the instants before the delay point detected to zeros as described in Fig. 2. With those modifications of the eigenvectors, we can use them as the initial weights after Fourier transformation for FDICA. The frame length in short time DFT is set to be 1,024 as described in [4], the frame shift is 16 taps, the window function is a Hamming window, and the step-size is set to be 1×10^{-4}.

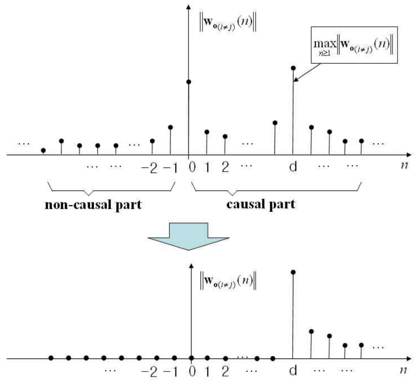

그림 2. 지연정보를 갖는 고유벡터의 수정 프로세서
Fig. 2 Modification processing of the eigenvector that has delay information.

Fig. 3 represent the eigenvalue polynomials and eigenvector polynomials for the case of (11). The delay information, (50, 100) also obtained at off-diagonal components in (b),(c) in Fig. 3.

$$\mathbf{A}_2 = \begin{bmatrix} 2 & z^{-100} \\ z^{-50} & 1 \end{bmatrix} \tag{11}$$

To perform experiments for various mixture cases, source signals were mixed with six different delayed systems. Table II presents various delay mixing cases.

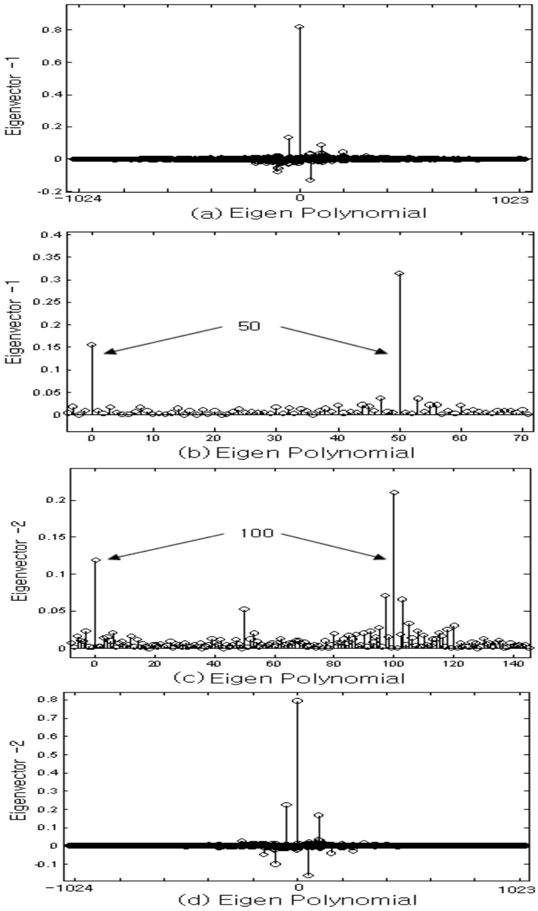

그림 3. 식 (11)에 대한 고유벡터 성분
Fig. 3 Eigenvector polynomials of Eq. (11)
(a)(c) : Eigenvectors of delay z^{-50}
(b)(d) : Eigenvectors of delay z^{-100}

표 1. 시뮬레이션을 위한 다양한 지연 혼합
Table 1. Various delayed mixtures for simulation

	case 1	case 2	case 3	case 4	case 5	case 6
d_1	0	2	10	31	50	100
d_2	0	3	15	41	100	50

In order to evaluate the separation performance, the SIR is used which is defined as in Eq. (12), which stand for signal to interference ratio. In this measuring tool, performance is the higher the better.

$$SIR = SIR_o - SIR_i \equiv 10\left[\log\frac{\sum_t |y_{ii}(t)|^2}{\sum_t\left(\sum_{i\neq j} y_{ij}(t)\right)^2} - \log\frac{\sum_t |x_{ii}(t)|^2}{\sum_t\left(\sum_{i\neq j} x_{ij}(t)\right)^2}\right](dB), \quad (12)$$

Fig. 4 shows the SIR results for different cases of delayed mixture when the separation performance is assumed to be saturated after 20-epoch. As seen, the SIR of FDICA obviously degrades when the delay becomes longer. The results reveal that the separation

performances of the proposed method are improving the SIR by about 1~3dB than that of FDICA on various delay conditions.

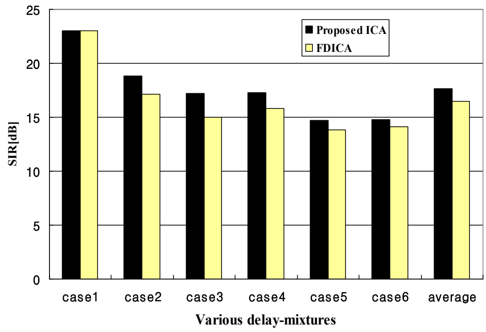

그림 4. FDICA 와 제안하는 방법의 수렴 후 SIR 비교
Fig. 4 Comparison of SIR' for FDICA and proposed method after convergence

Fig. 5 displays the SIR's of BSS algorithms with 10 epochs on the horizontal axis of the figure. The SIR learning curves of the case 3 and of the average of all cases in Table II are shown to compare convergence performance. The proposed method achieved an improvement of the converging speed over FDICA. Especially, in early adaptation with 1 or 2 epochs, the proposed method improves the separation performance of FDICA by about 6 dB. It is notable that the proposed method requires fewer epochs than those of the FDICA, which is encouraging for real time processing.

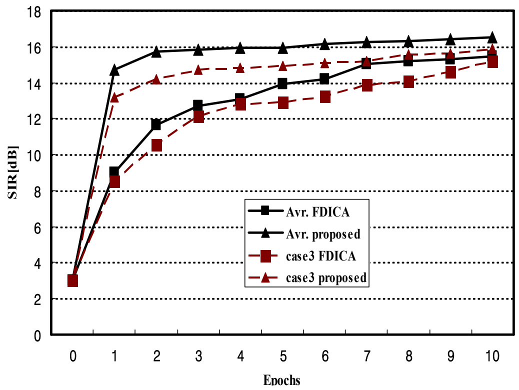

그림 5. 반복수렴실험(epoch)에 대한 SIR 비교 (수렴속도비)
Fig. 5 SIR comparison versus the epochs (Convergence speed rate)

V. Conclusion

In this paper, an initial weight establishment method for FDICA of delayed mixture is proposed to improve the performances of FDICA. After analytic eigendecomposition, it can be proved that the delay information can be obtained from the eigenvector polynomials. Those eigenvector polynomials with delay information are used as initial weights and overcome the disadvantage of epoch in FDICA algorithm. In steady state, the proposed method can achieve the improvement in SIR by about 2~3dB over that of FDICA. Especially, in early adaptive state (i.e., 1 or 2 epoch), the SIR's are improved about 5~7dB. The results of the signal separation experiments reveal that the separation performance is improved and even the convergence performance is considerably improved. It could be noticed that the proposed algorithm can be useful even in the noisy situation with more than 10dB in SNR.

References

[1] Chang-ki Lee and Dae-ik Kim, "Adaptive Noise Reduction of Speech Using Wavelet Transform", The Journal of The Korea Institute of Electronics Communications Sciences, Vol. 4, No. 3, pp. 190-196, 2009.

[2] Jae-seung Choi, "Speech and Noise Recognition System by Neural Network", The Journal of The Korea Institute of Electronics Communications Sciences, Vol. 5, No. 4, pp. 357-362, 2010.

[3] H. Saruwatari, T. Kawamura and K. Shikano, "Blind source separation for speech based on fast-convergence algorithm with ICA and beamforming," Proc. Eurospeech 2001, pp. 2603-2606, Sep. 2001.

[4] A. J. Bell and T. J. Sejnowski, "An information-maximization approach to blind separation and blind deconvolution," Neural Computation, Vol. 7, No. 6, pp. 1129-1159, 1995.

[5] Tomoya Takatani, Satoshi Ukai, Tsuyoki Nishikawa, Hiroshi Saruwatari and Kiyohiro Shikano, "A Self-Generator Method for Initial Filters of SIMO-ICA Applied to Blind Separation of Binaural Sound Mixtures," IEICE Transactions 88-A(7) : pp. 1673-1682, 2005.

[6] Sang-hyun Park, "An Effective Steel Plate Detection Using Eigenvalue Analysis", The Journal of The Korea Institute of Electronics Communications Sciences, Vol. 7, No. 5, pp. 1033-1039, 2012.

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