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Based on SVD-EMD-ICA, Source of Vibration Identification Caused by Bearing Faults

[1]Soumya Pradhan
Gandhi Institute of Excellent Technocrats, Bhubaneswar, India
[2]Satyam Das
Adarsha College of Engineering, Angul, Odisha, India

Abstract
Aiming at the sensitivity to noises and the underdetermined number of signal in a single channel signal BSS (blind source separation), a high accuracy method of BSS was proposed through the proper combination of SVD(singular value decomposition) , EMD(empirical model decomposition) and ICA(independent component analysis). The Hankel matrix, which was constructed through the single, was decomposed by SVD to get singular values series. The crucial singular values were selected based on the maximum value in different series to reconstruct the vibration signal. The reconstructed signal was decomposed by EMD to get IMFs (intrinsic model functions), which were regarded as the supplementary channels of ICA. FastICA was applied to execute the blind source separation on the condition of numbers ascertained by the principle called as Bayes information. The method was verified through a lot of simulation and test data about bearing faults, the result shows that the method could effectively isolate the vibration sources caused by different fault model.

Keywords: *SVD; EMD; BSS; Fault model identification.*

I. Introduction

Bearing system has the interaction of inner ring, rolling body, outer ring and cage, there is generally a combined incentives of more failure modes of faulty bearing. Therefore, the fault source separation is the key to bearing fault detection correctly. But in practical engineering, the bearing vibration detection generally can only detect the vibration signals of the single channel due to space constraints. Multi-fault sources separation of bearing is a single-channel blind source separation problem.

However, the separation of single-channel signal is a typical underdetermined blind source separation Problem [1]. The number of sensor significantly less than the number of vibration source, to which many domestic and foreign scholars, respectively, has put forward many signal channel supplementary methods to solve the underdetermined separation, turning it into the general separation well-posed problem. As the literature[2] proposed a use of phase space reconstruction and singular value decomposition to realize the underdetermined blind source separation, the method has large human factors in selecting singular value during the inverse transformation. Literature[3] presented a blind separation method based on wavelet packet decomposition of the related mechanical vibration source, the decomposition order of wavelet packet affects the separation result of blind source separation. Literature[4] studied the underdetermined blind source separation deeply based on sparse representation, and [5] proposed the median clustering algorithm to implement the underdetermined blind source separation, the two methods are based on the representation of source signal, the separation effect is not ideal when the source signal has weak sparsity. In order to decrease the uncertainty of analysis results which is brought by sparse decomposition in enhancing signal channel, the empirical mode

decomposition was introduced to the single-channel signal blind source separation in literature[6, 7], which can decompose the non-stationary signalnto a series of stable and stationary signals of single mode, and the decomposed multi-scale signals can be used as virtual channel of blind source separation, which can successfully separate the bearing and gear fault vibration source. But the precision of empirical mode decomposition and the correctness of modes are affected greatly by the noise[8].

However, the noise is inevitable in practical engineering. To make full use of the adaptive feature of EMD in signal channel supplementary in blind source separation, and eliminate the defect of EMD to noise. The SVD is introduced to the study of EMD and BSS, the paper proposes a method for single-channel BSS based on SVD-EMD-ICA. Hankel matrix is constructed for single-channel signal and singular value decomposition of the matrix, make use of the singular values difference spectrum unilateral maximum principle as the key selection criterion to improve the signal-to-noise ratio of the reconstructed signal, EMD is applied to the reconstructed signal to get multi-scale intrinsic mode functions, which can be used as a signal enhanced channel, and the Bayesian criterion is used to estimate the source number, archive the single-channel BSS by FastICA algorithm. Finally, the simulation data and experimental data for the verification of the proposed method and model.
The paper is organized as follows. In Section 2, a brief introduction of the proposed method, including SVD and EMD. After the presented recognition model in Section 3, a experimental verification, including simulation data and experimental data, of the presented model is carried on in Section 4, while its effectiveness is evaluated in comparison with the EMD-ICA method. Conclusion is presented in Section 5.

II. BSS method based on SVD-EMD-ICA

2.1 De-noising principle of SVD based on Hankel matrix

Supposed the analysis signal $x = [x(1), x(2), \Lambda, x(N)]$, in which N is the length of signal, constructing a $m \times n$ dimensional Hankelmatrix [9] as followed

$$H = \begin{bmatrix} x(1) & x(2) & \Lambda & x(n) \\ x(2) & x(3) & \Lambda & x(n+1) \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ x(m) & x(m+1) & \square & x(N) \end{bmatrix} \tag{1}$$

where $1< n < N$, $m = N - n + 1$.
For a real matrix $H \in R^{m\times n}$, regardless of whether its row-column is relevant, there must be an orthogonal matrix $U \in R^{m\times m}$ and an orthogonal matrix $V \in R^{n\times n}$ satisfy the formula as followed

$$H = USV^T \tag{2}$$

where $S = (diag(\sigma_1, \sigma_2, \Lambda, \sigma_q), \mathbf{0}) \in R^{m\times n}$

in which $\mathbf{0}$ represents zero matrix. $q = \min(m, n)$, and $\sigma_1 \geq \sigma_2 \geq \square \geq \sigma_q$, formula (2) is the singular value decomposition, and $\sigma_i (i = 1, 2, \Lambda, q)$ are the singular values of matrix H [10].

III. Conclusions

1) Organic integration of SVD, EMD and ICA, using the noise reduction function of SVD, and EMD can convert non-stationary model into stable vibration mode, and the source separation ability of ICA, has realized the blind source separation of single-channel noised signal.
2) The proposed method is applied to bearing vibration source identification study, successfully recognized the fault vibration characteristics of the bearing outer ring, and adapt to the bearing fault signal analysis.

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