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Single channel blind source separation on the instantaneous mixed signal of multiple dynamic sources

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ABSTRACT

Single Channel Blind Source Separation (SCBSS) has had many algorithms for artificial mixed signal, where the number of mixing sources is assumed to be known, and mixed signal used in validation algorithm only contains two signal sources. However, in real-world application, the mixed number of sources is unknown and is usually more than two. This paper presents a new single-channel blind source separation algorithm based on the multi-channel mapping and Independent Component Analysis (ICA), which supposes that mixed signal comes from a dynamic system in which any component depends on the interaction of other components and signals are linear instantaneous mixture. The mathematical model demonstrates the single channel signal of linear instantaneous mixture. In order to map single channel signals into multi-channel signals, Takens theory and C-C method are used to estimate the time delay and the embedding dimension in the time series of the dynamic system. FastICA for multi-channel blind source separation is improved by using FSS-Kernel (Finite Support Samples Kernel), where the nonlinear function of FastICA is replaced by PDF (probability density function) and estimated by FSS-Kernel. The experiments are conducted to evaluate the proposed algorithm of single channel blind source separation, in which the synthetic signals and speech signals are used respectively. The experiment results show that the proposed method is very effective to estimate the number of independent components and is practical to separate two or more mixed signals.

1. Introduction

Single Channel Blind Source Separation has received much attention in the area of signal process because using one sensor (single channel) can greatly reduce the cost. Moreover, in some measurement-control fields, the use of multi sensors are restricted due to the limited space, such as the fault diagnosis of machinery and the monitoring of grinding machine. In the acoustic detection field, under some circumstances, only one sensor is allowed to use for collecting signals and separating the ship radiated noise from marine environment noise. In the biomedical field, the Electro encephalon gram (EEG) signals features need to be extracted from a single signal which is often mixed with many interference signals, such as electrocardiogram(ECG), electromyography(EMG) and eye movement artifact (electrooculogram, EOG), etc.

Therefore, how to extract useful signals from the observed signal collected by one single sensor is a SCBSS problem [1–3,25,29]. The aim of separation is to recover the source signals or sources from mixed signal through a conversion [4].

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The SCBSS is a challenging task because it is the extreme case of underdetermined blind source separation [5,6]. It is a pathological problem to estimate multiple signals with only one channel signals.

This paper presents a new SCBSS algorithm. The main idea is to regard the signal collected from single sensor as a component of the dynamic system. Based on Takens theory, single channel time series collected by the single sensor can be used to recover the original dynamic system [7]. Through the phase space reconstruction technique, which is based on C-C method, single channel signals will be mapped into multi-channel signal after estimating the source number (embedding dimension) and delay time of single channel signal. In this way, more mature blind source separation algorithms for multi-channel signals could be used to recover source signals. Based on the FastICA fusion algorithm of FSS-Kernel (Finite Support Samples Kernel), the separation of multi-channel signals is achieved. The contribution of this paper is that it can not only separate the single channel signals but also estimate the number of the independent sources, which avoids using the inefficient trial and error method to determine the number of independent sources.

2. Related work

In the last decade, SCBSS has received much attention in academic fields. In the early stages, mixed signal can be separated through pulse correlation adaptive filtering, Fourier transform and wavelet transform. The nature of these methods is transform-domain filtering. Hopgood and Rayner [5,6] have made great achievements in this regard. They not only answered the question of separability, but also proposed a method of constructing a separable transform domain. However, in order to separate the mixed signal in transform domain, various parameters of the source signals need to be known or estimated. Meanwhile, the separation performance was greatly influenced by the accuracy of parameters. Since 2002, Jang et al. [8] proposed a SCBSS algorithm which adopted time-domain basis function. The main idea is utilizing intrinsic time structure of source signals to study prior time-domain basis function sets. However, in actual situations, source signals are generally unknown. Therefore, it is difficult to construct a basis function to describe the structure of the signal. In [9], C James put forward that according to the frequency of measured signals, the method of dynamic embedding can be used to construct delayed matrices. Then, the reconstructed multi-channel signals can be separated through Independent Component Analysis (ICA). Nevertheless, the method is not applicable in practice because the frequency of measured signals is not easily determined.

The method which firstly adopts multi-channel mapping technique and then uses blind source separation is a widely used SCBSS algorithm, which has attracted wide attention from scholars [9]. Ref. [10,30] used wavelet-ICA algorithm to solve the SCBSS. Firstly, single channel signal was transformed into multi-channel signals through wavelet decompositions and reconstructions. Then, FastICA was applied to extract independent components from multi-channel signals. The algorithm could deal with non-stationary problems, but the separation performance would be affected by the selection of wavelet basis functions and optimum of wavelet decomposition layers. Ref. [11] adopted EMD-ICA algorithm which uses Empirical Mode Decomposition (EMD) to map single channel signal to multiple Intrinsic Mode Functions (IMF). Then, multi-channel signals were constructed according to source number. Finally, source signals could be extracted through ICA algorithm. The EMD-ICA algorithm could separate non-linear, non-stationary and even chaotic single channel signals. However, EMD had poor anti-aliasing effect, and it didn't work when the source signals were not Intrinsic mode functions. To improve it, ensemble empirical mode decomposition (EEMD) was used to decompose single channel signal [12]. On the basis of EMD, a data analysis method of white noise was proposed to overcome the poor anti-aliasing effect. As a fast iterative algorithm, FastICA can be applied to any types of data, which makes it possible to process high dimensional data. EEMD-FastICA algorithm can converge quickly, but there is no standard criterion for reconstructing multi-channel signals. Therefore, human judgments are still important.

In general, the premise of the multi-channel blind separation technique is the accurate mapping from single channel signals to multi-channel signals. The adoption of single signal multiplexing mapping technique mentioned above needs prior information about the number of source signals. The number of sources needs to be known or determined by the third party source number estimation algorithm. In a dynamic system, the C-C method of phase space reconstruction technique can map the mixed sources into the only multi-dimension space without human intervention. Phase space reconstruction technique was raised and proven by Takens to help restore the original power system from time series. Nowadays, it has been widely used in the space reconstruction of chaotic time series, and has become the theoretical basis for processing chaotic time series. Signal is the function of time, which represents the movement law of certain physical quantity and multiple signals interacting within a certain system forms a dynamic system. Therefore, we can regard the mixed source signals collected from one single sensor as the signals from the same power system. According to the theory of phase space construction, phase space reconstruction can help map the single channel signal to multi-channel signals.

As for the multi-channel signals, the proven ICA and FastICA algorithm can work well. FastICA is an adaptive multi-channel signal processing algorithm developed from ICA. FastICA algorithm can avoid disadvantages of the traditional ICA algorithm, such as the slow convergence speed due to the use of gradient descent method. The adaptive processing and the batch processing are combined together in the derivation of the calculation method, which makes the algorithm converges faster than batch processing and even faster than some adaptive algorithms. However, the selection of nonlinear function is crucial but difficult, if the nonlinear function is selected wrongly, FastICA algorithm may be trapped in the local extreme and lead to poor separation performance. FSS-Kernel method can estimate the probability density

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