A Kurtosis-based Algorithm for Blind Sources Separation Using the Cayley Transformation And Its Application to Multi-channel Electrogastrograms

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Abstract

This paper presents a new kurtosis-based algorithm for blind separation of convolutively mixed source signals. The algorithm whitens the signals not only spatially but also temporally beforehand. A separator is built for the whitened signals and it exists in the set of para-unitary matrices. Since the set forms a curved manifold, it is hard to treat its elements. In order to avoid the difficulty, this paper introduces the Cayley transformation for the para-unitary matrices. The transformed matrix is referred to as para-skew-Hermitian matrix and the set of such matrices forms a linear space. In the set of all para-skew- Hermitian matrices, the kurtosis-based algorithm obtains a desired separator.

This paper also shows the algorithm's application to electrogastrogram datum which are observed by 4 electrodes on subjects' abdomen around their stomachs. An electrogastrogram contains signals from a stomach and other organs. This paper obtains independent components by the algorithm and then extracts the signal corresponding to the stomach from the data.

1. Introduction

Blind source separation (BSS) is a technique to estimate the original signals only from their mixture, without any knowledge about mixing process. It has attracted a great deal of attention of researchers in signal processing and the other fields and its applications have been reported.

In view of complexity, the mixing processes are classified into two categories: instantaneous mixture of sources and convolutive mixture of sources. Although the former was mainly researched, the researchers are recently interested in the latter. However, the estimated parameters for BSS of convolute mixture of sources are more than those for the instantaneous mixed sources. Algorithms of BSS are roughly classified into the methods based on information-theoretic approaches and those based on cumulants of the separator's outputs. An algorithm we propose in this paper is based on the latter type.

For instantaneous mixture of sources, the observed signal is spatially whitened in advance and a separating matrix is found in the class of orthogonal matrices, which transform white signal to other white signal. The degree of statistical independency between the separator's outputs can be evaluated by their cross cumulants. Common [5] describes that minimization of the square sum of the entire cross cumulants is equivalent to maximization of the square sum of the auto cumulants (or kurtosis) of the outputs. The merit of this approach is that no a priori knowledge on statistical properties of the source signals is required. If there is knowledge on whether the sources being sub-Gaussian or super-Gaussian, the problem becomes easy and is equivalent to evaluating the sum of the kurtosises of the outputs.

When the kurtosis-based algorithm is extended to BSS of convolutive mixture of sources, a serious difficulty arises. Namely, the searching space for the separator becomes the set of para-unitary matrices (orthogonal transfer function matrices) and the extension yields much more computational burden. In order to overcome the problem, this paper exploits the Cayley transformation, which maps the set of para-unitary matrices to the set of para-skew Hermitian matrices. While the former set forms a curved manifold, the latter set forms a vector space and is easy to treat.

Section 2 describes the formulation of blind separation of convolutively mixed source signals. Section 3 introduces the Cayley transformation. Section 4 describes a kurtosis -based algorithm, Section 5 shows an application of the algorithm to an electrogastrogram.

2. Mixing Process and Demixing Process

Consider the situation that N sources generate mutually independent random signals $s_i(t)(i=1,\ldots,N)$ at a discrete time t and $s_i(t)$ ($t=\ldots, -1, 0, 1, \ldots$) is iid (independent identically distributed) and non-Gaussian. In order to simplify our problem, we assume that the sources all have zero mean and unity variance. N sensors receive convolutive mixture of the sources. Let the received signals denote $x_j'(t)$ ($j=1,\ldots,N$) and then the convolutively mixing process is expressed as

$$\mathbf{x}'(t)=\mathbf{A}'(z)\mathbf{s}(t), \qquad (1)$$

where $\mathbf{s}(t)=[s_1(t), \ldots, s_N(t)]^T$ and $\mathbf{x}'(t)=[x'_1(t), \ldots, x'_N(t)]^T$