ABSTRACT

This article evaluates the outlier sensitivity of five independent component analysis (ICA) algorithms (FastICA, Extended Infomax, JADE, Radical, and β-divergence) using (a) the Amari separation performance index, (b) the optimum angle of rotation error, and (c) the contrast function difference in an outlier-contaminated mixture simulation. The Amari separation performance index has revealed a strong sensitivity of JADE and FastICA (using third- and fourth-order nonlinearities) to outliers. However, the two contrast measures demonstrated conclusively that β-divergence is the least outlier-sensitive algorithm, followed by Radical, FastICA (exponential and hyperbolic-tangent nonlinearities), Extended Infomax, JADE, and FastICA (third- and fourth-order nonlinearities) in an outlier-contaminated mixture of two uniformly distributed signals. The novelty of this article is the development of an unbiased optimization-landscape environment for assessing outlier sensitivity, as well as the optimum angle of rotation error and the contrast function difference as promising new measures for assessing the outlier sensitivity of ICA algorithms.

Keywords: higher order statistics; independent component analysis; outliers; robust statistics

INTRODUCTION

Functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) signals are two standard tools for investigating brain activity and, in turn, human cognition, as studied in cognitive informatics (Zhang, Wang, & Kinsner, 2007) and other disciplines. Of particular interest are the location of various activities within the brain and the dynamics of those functional regions as observed through the EEG signal. While fMRI shows the location of the active brain regions reasonably well, the recorded temporal EEG signal may not be a good indicator of the dynamics because it does not originate from the brain alone, but is a mixture of the EEG itself with the electrocardiogram (ECG) representing heart activity and the electromyogram (EMG) caused by the activity of the muscular system. In addition, the EEG and EMG signals have non-Gaussian probability distribution functions (pdfs) and broadband coloured noise-like frequency spectra. Consequently, to reduce the impact of such unwanted signals, demixing of the recorded EEG signal should be used. A technique called independent component analysis (ICA) can demix the recordings in...
order to analyze them as close to their pure forms as possible (Gadhok, 2006; Hyvärinen, Karhunen, & Oja, 2001; Makeig et al., 2002; McKeown et al., 1998).

However, various ICA algorithm implementations are sensitive to outliers (i.e., the extreme values that do not comply with the pdf of the signal) because the implementations are based on high-order statistics that include moments higher than two. In fact, contamination of biomedical recordings by outliers is an unavoidable aspect of signal processing. For example, Hampel, Ronchetti, Rousseeuw, and Stahel (1986) provided a real-world situation related to EEG data obtained by a fully automatic recorder. The recorder equipment was working properly and the histogram was adequate except for some seemingly unimportant jitter of the plotter in the tails in the pdf. Yet, the third and fourth moments were far too large. A search revealed that there was a spike of about two dozen out of a quarter million data points when the equipment was turned on, and these few points caused the high moments and the jitter in the plot. Thus, the impact of outliers on the signal separation performance of an ICA algorithm is an important characteristic in assessing the algorithm’s utility for cognitive informatics.

Blind source separation (BSS) is defined as the problem of demixing an additive combination of statistically independent signals based on observations of those mixtures only. ICA is a statistical method for extracting sources from their mixtures without the knowledge of the sources themselves. It uses the information contained in the higher order statistics of the observed mixtures, under the assumption of non-Gaussian distributed sources, to separate the signals into their original sources up to an arbitrary scale and permutation (Hyvärinen et al., 2001).

The objective of this article is to study the outlier sensitivity of ICA algorithms in an unbiased optimization-landscape environment by measuring their separation performance and changes to their respective contrast functions (ICA estimators) in an outlier-contaminated simulation. This is a novel approach as most ICA outlier robustness research has been concerned with either the boundedness of the influence function (IF) of an ICA estimator, or the separation performance in a biased optimization-landscape environment with outlier-contaminated simulations (Hampel et al., 1986; Hyvärinen et al., 2001; Minami & Eguchi, 2003).

Unfortunately, the boundedness of the IF does not give a direct answer to the question of how sensitive the separation performance is to outliers, and in simulations the potential suboptimal searches of the ICA optimization landscape (by techniques such as a quasi-Newton method, or rotation or exhaustive search, depending on the algorithm, along with unfair simulation conditions) lead to inconsistent results for the comparison of ICA estimators. The aim of this article is to go halfway between the theoretical and empirical measurements by evaluating the outlier sensitivity through (a) the Amari separation performance index (API), (b) the optimum angle of rotation error, and (c) the contrast function difference in an outlier-contaminated simulation with fair optimization conditions for the algorithms. Computational demands are not considered because they do not impact the rotation sensitivity analysis.

The data set studied is a mixture of two uniform distributions due to its ability to reveal outlier sensitivities. Outliers are selected based on the number of standard deviations, $\sigma$, from the mean of the distribution. Thus, when an outlier distributional model is applied, the risks can be assessed. Finally, the article studies the FastICA (fast fixed-point ICA), Extended Infomax, JADE (joint approximate diagonalization of eigenmatrices), Radical (robust, accurate, direct, independent component analysis algorithm), and $\beta$-divergence ICA algorithms’ contrast functions due to their popularity in research and their claimed outlier robustness in literature (Cardoso, 1999; Hyvärinen et al., 2001; Learned-Miller & Fisher, 2003; Lee, Girolami, & Sejnowski, 1999; Mihoko & Eguchi, 2002).
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