Editorial

Blind signal separation and independent component analysis

Independent component analysis (ICA) is emerging as a new paradigm in signal processing and data analysis. ICA has been proposed as a solution to the blind source separation problem (BSS) in which sensory signals are given as mixtures of unknown source signals. Since neither the sources nor the mixing environment are known a priori there is no general analytical solution to this problem. However, since the last decade researchers have found good approximate solutions based on assumptions about the source statistics. They were able to formulate solutions or algorithms that were derived from well-known cost functions including maximum likelihood estimation, information maximization and higher-order cumulants. The ICA framework touches many theoretical research areas, and therefore receives attention in several research communities including machine learning, neural networks, statistical signal processing and Bayesian modeling. More recently, there have been numerous applications of ICA in adaptive filtering, speech signal processing, biomedical signal processing, computational neuroscience, image coding, text data modeling, and financial data analysis. The standard ICA formulation has, in general, strong assumptions or simplifications such as: the number of sensors has to be equal or greater than the number of sources, there is no additive noise signal in the sensors, and the sources are modeled as random variables. However, when applying ICA to real-world problems it becomes evident that those restrictions are cumbersome and although the standard ICA algorithms give good approximate solutions, there is great need in going beyond the standard assumptions and develop new algorithms that can relax some of the assumptions.

This special issue on ICA and BSS is a timely publication covering important recent findings in ICA theory as well as new applications of ICA in data analysis. Leading researchers present their work to advance this field beyond traditional borders and show how this field can bridge disciplines and yield new methods that lead to mutual benefits and advances in science and engineering. This issue is composed of a review article and two parts: the first part presents new theoretical findings while the second part presents novel applications. Often, there is no such sharp division into these two parts since illustrative simulations support theoretical findings and practical methods include algorithmic modifications to design and evaluate the application-specific methods.

In “Frontiers of research in BSS/ICA”, V. David Sánchez A. formulates some of the basic concepts and problems in the areas of blind signal separation and independent component analysis. He then moves to a concise description of key methods of data preprocessing and algorithms that provide solutions to the instantaneous mixture and the
convolutive mixture as well as time- and frequency-domain algorithms. A comparative assessment of some representative algorithms is provided. Finally, he presents current and open areas of basic and application research. The latter presentation includes theoretical investigations and novel practical applications. The theoretical investigations include, among others, evolving solution approaches to the overcomplete, non-linear, noisy, and non-stationary cases. Novel applications of these exciting fields of study include applications in the areas of speech enhancement, medical signal processing, biological modeling of feature extraction, communications, remote sensing, and time series analysis.

1. Theoretical contributions

There are several papers in this issue that consider new theories to solving the blind source separation problem. New formulations of new cost functions and derivation of new learning algorithms include novel entropy measures, geometric considerations or Bayesian approaches. The convergence properties as well as the asymptotic stability of the ICA algorithm is of major concern and several papers address this problem by presenting an in-depth analysis and simulation results. In an effort to extend standard ICA formulations into new research directions there are papers that discuss ICA in the framework of efficient coding using sparse source densities for signal decomposition, feature extraction and overcomplete representation.

In “Blind source separation using Renyi’s α-marginal entropies”, Erdogmus, Hild II, and Principe consider the Renyi’s alpha entropy, instead of the well-known Shannon entropy, for obtaining algorithms of blind source separation. To obtain practical algorithms, the Parzen window method is applied to estimate the relevant densities. In computer simulations they compare the performances of their new algorithm and show how it depends on the values of alpha.

A geometric-based approach to the BSS problem for symmetrical non-uniform sources for linear and non-linear mixtures is proposed by Puntonet, Mansour, Bauer, and Lang in “Separation of sources using simulated annealing and competitive learning”. The space of mixtures is divided in concentric spheres in order to obtain the independent axes in each sphere adaptively by means of symmetrically distributed neurons in each dimension. In such a way the non-linear problem is solved by a multiple linearization method. The learning rule is obtained from a competitive learning technique and a simulated annealing preprocessing is proposed to speed the convergence.

In “Blind signal separation in noisy environments using a three-step quantizer”, Mathis and Joho are looking at blind signal separation in noisy environments. They use a three-step quantizer in order to suppress the bias due to noise. Stability analysis and simulation results of their new non-linear function are presented.

In “Blind deconvolution using temporal predictability”, Stone considers the problem of blind deconvolution that is closely related to blind source separation. He introduces a new approach based on temporal predictability, inspired from the observation that physical environments tend to act like smoothing filters, and thus increase the predictability of signals.
Two papers suggest new algorithms by investigating an important issue in ICA namely the convergence properties and the stability of the algorithms.

Cruces, Castedo, and Cichocki propose an approach for “Robust blind source separation algorithm: using cumulants”. Their method is based on considering saddle-points of a cumulant-based cost function, and leads to unbiased estimators even in the presence of Gaussian noise. Even more precise estimators can be obtained by incorporating second-order statistics in the estimation process.

In “Adaptive step-size control in blind source separation”, von Hoff and Lindgren put forward an approach to adaptive step-size control in blind source separation. The proposed algorithm is analyzed in terms of its stability and its local properties in the vicinity of the true solution. An error-dependent step-size control approach is proposed.

S. Akaho proposes “Conditionally independent component analysis for supervised feature extraction”. By adding the conditional independence between input and output variables, he derives an alternate naive Bayes learning rule. Experiments demonstrate better performance than standard naive Bayes rule for small data sets.

In “Imposing sparsity on the mixing matrix in independent component analysis”, Hyvärinen and Karthikesh impose a Bayesian prior of sparseness of the mixing matrix parameter in ordinary ICA. They show that many existing ICA algorithms can directly use such a prior by means of a virtual sample.

In “Extraction of a source from multichannel data using sparse decomposition”, Zibulevsky and Zeevi show improved source separation performance from multichannel data by assuming that signal dictionaries are known a priori. This method is applicable to problems where rough templates of the source are available. Experiments are reported for synthesized evoke-related MEG data.

A. Utsugi presents in “Independent components of natural images under variable compression rate” a generalized ICA model with variable sparsity. The model allows overcomplete bases and additive noise in the observables and is applied to natural image data. Independent components that resemble Gabor functions emerge during the experiments which is consistent with previous studies. The aspect ratios of the optimal bases increase with noise level and degree of sparsity as the dominant features change from textures to contours.

S. Deligne and R. Gopinath address in “An EM algorithm for convolutive independent component analysis” the problem of blind signal separation of convolutive mixtures where the density of the sources is modeled with Gaussian mixtures. An expectation maximization (EM) algorithm is proposed that estimates the source densities and the separating filters. Multichannel autoregressive spectral estimation techniques are used to estimate a starting point for the EM algorithm. Experiments with artificial mixtures verify the proposed approach.

2. Novel applications

The use of the ICA algorithm becomes significant in many applications and this issue’s focus is on application of ICA to biomedical data analysis, speech signal processing and communication systems. Biomedical data analysis is a challenging research
area and requires novel signal processing approaches such as ICA. This issue considers
the analysis of brain signal recordings using MRI and MEG. Applications to cardiac
signals as well as the analysis of neuronal activities are described. In speech sig-
nal processing, new methods for multichannel blind deconvolution for robust speech
recognition in noisy environment as well as speech coding for speaker recognition are
proposed. Applications in communication consider adaptive filtering and fast converge
issues.

In “Analysis of functional neuroimages using ICA with adaptive binary sources”,
Højen-Sørensen, Winther, and Hansen use the log-likelihood (Bayesian information
criterion, BIC) measure to find the number of sources contained in the raw data. Then,
they apply a cavity mean field algorithm, accompanied with a Gaussian noise model
to obtain ICA components that are possibly task- or response-related components.

In “Spatio-temporal decorrelated activity patterns in functional MRI data during real
and imagined motor tasks”, D.W. Dong, J.A.S. Kelso, and F.L. Steinberg describe an
analytical method for source separation based on event spatio-temporal decorrelation.
No assumptions about the temporal scale nor about the event probability distribution
are made. The algorithm is capable to separate multiple task-related brain activities
revealed in functional magnetic resonance imaging (fMRI) signals.

In “Spatial independent component analysis of functional magnetic resonance imag-
ing time-series: characterization of the cortical components”, Formisano, Esposito,
Kriegeskorte, Tedeschi, Di Salle, and Goebel employ a cortex-based ICA, i.e. the use
of anatomical images and the Brain Voyager software to select voxels on the cortex
surface for further ICA analysis. Then they propose three criteria to select ‘interesting’
ICA components.

In “Independent component analysis for unaveraged single-trial MEG data decom-
position and single-dipole source localization”, Cao, Murata, Amari, Cichocki, and Takeda
apply ICA to decomposition and localization of single-trial MEG data with better accu-

In “Extracting the fetal heart rate variability using a frequency tracking algorithm”,
Barros presents an algorithm that finds the fetal heart rate variability (HRV) from
mother’s ECG using ICA. The methodology consists of a separation algorithm and a
measure for HRV that is called heart instantaneous frequency.

An application of ICA/BSS methods to neuroinformatics is considered in the paper
“Classification of neuronal activities from tetrode recordings using independent com-
ponent analysis” by Takahashi, Sakurai, Tsukada, and Anzai. The authors consider the
problem of classifying spike shapes to extract single neuronal activities from multi-unit
recordings. ICA is found to solve problems associated with simultaneous spiking.

Choi, Hong, Glotin, and Berthommier present in “Multichannel signal separation
for cocktail party speech recognition: a dynamic recurrent network” a mathematical
framework for using only the cross feedback filter for speech separation. They present
a new learning rule and experimental results in automatic speech recognition.

In “Top-down attention to complement independent component analysis for blind
signal separation”, Bae, Park, and Lee formulate an attention aspect to complement
an existing ICA algorithm for improved blind signal separation for processing spoken
words in a real-world noisy environment. Neural networks mimics top-down attention processing and provides additional information on speech signal. Independent component analysis can be applied for feature extraction, in addition to the more conventional blind source separation.

In “Learning statistically efficient features for speaker recognition” by Jang, Lee, and Oh ICA is used to extract an optimal basis for representing speech signals. The features are used in speaker recognition where the authors report recognition rates that are superior to what can be obtained by conventional Fourier-based methods.

In “Blind separation of rotating machine sources: bilinear forms and convolutive mixtures”, Ypma, Leshem, and Duin apply BSS to extract a machine signature from distorted measurements of rotating machines. Both acoustic and vibration monitoring experiments are reported.

ICA can improve performance in communications applications. The paper “Multi-tag radio-frequency identification systems based on new blind source separation neural networks” by Deville, Damour, and Charkani deals with the performance improvement of multi-tag radio-frequency systems. The authors propose a two-input two-output model for a separation system. They present real and artificial experiments that support and justify the proposed approach.

In “Median equivariant adaptive separation via independence: application to communications”, Murillo-Fuentes and González Serrano propose a new modification of the learning algorithm (EASY) to obtain a more robust convergence in communications systems. To this end, the paper introduces a new parameter, and a new stability analysis is worked out including this new parameter.

We would like to express our thanks to all colleagues that submitted their research work for prospective publication in this special issue of Neurocomputing and our team of referees for their excellent work.

Enjoy the contributions!

S.-I. Amari, Aapo Hyvärinen,
Soo-Young Lee, Te-Won Lee,
V. David Sánchez A
The Guest Editorial Team
P.O. Box 1424, La Cañada,
CA 91012-1424, USA

E-mail address: vdavidsanchez@earthlink.net (V. David Sánchez A)