TOWARDS INDUSTRIAL APPLICATIONS OF BLIND SOURCE SEPARATION AND INDEPENDENT COMPONENT ANALYSIS

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ABSTRACT

This paper first presents a short overview of applications of Blind Source Separation (BSS) and Independent Component Analysis (ICA), with main emphasis on the topics addressed in the frame of the ICA'99 workshop, and esp. of its "Industrial applications" session. The relationships between algorithmic, application and hardware developments in the BSS and ICA fields are then discussed.

1. BSS AND ICA APPLICATIONS IN THE FRAME OF ICA'99

Only a few years ago, the first papers were published about concepts and methods for two closely connected problems, i.e:

- Blind Source[1] Separation (BSS)
  (see esp. [1], and [2] followed by [3]-[4]),
- Independent Component Analysis (ICA)
  (see esp. [3]-[4] and [5] followed by [6]).

Since then, these topics have received increasing attention, and they are now becoming mature fields inside the area of signal processing and data analysis. This is reflected in ICA'99, which is believed to be the first workshop where (in addition to advanced theoretical contributions) so much emphasis is put on real-world applications of BSS and ICA methods.

The applications considered in ICA'99 cover a wide range of domains. Three of these fields are especially prominent, namely:

1. radiocommunications (in a broad sense),
2. speech and audio applications,
3. biomedical applications.

The latter two fields are resp. the topics of two dedicated sessions and are therefore not discussed in detail in this introductory paper. A third application-oriented session, called "Industrial applications", is also organized in the frame of ICA'99. The scope of this session is twofold. It first includes the above-mentioned papers on radiocommunications, which address problems ranging from mobile [7]-[8] and ionospheric HF [9] communication to people identification[2] [10]. But, beyond that specific domain, this session is also an opportunity to show the variety of applications to which BSS and ICA methods give rise. This is illustrated by three other presentations in this session, which resp. concern:

1. The identification of the chemical components contained by a sample, performed by applying BSS algorithms to Nuclear Magnetic Resonance spectroscopy signals [11].
2. The separation of two infrared optical sources, with a system which uses a beam splitter and two photodetectors to create two mixed signals [12].
3. An application of rotating machine vibration analysis methods to a submersible pump, including a benchmarking of ICA and other algorithms [13].

It should be mentioned that some application-oriented papers are also included in poster sessions. Some of them concern above-mentioned fields (see e.g. the application to rotating machine monitoring reported in

[1] Or "Signal".

[2] The system considered in [10] is an extension of the one discussed hereafter in Section 2.

[14]), whereas others address completely different topics (such as the denoising of a signal emitted by a laser diode and received by pyroelectric sensors [15]).

Clearly, various theoretical papers presented in this workshop also contain validations, often performed on toy problems or synthetic data, but sometimes with already realistic "applications" (see e.g. image denoising in [16] or applications of data mining tools to synthetic oil pipeline monitoring and forged banknotes detection in [17]). However, we cannot introduce all of them in detail in this paper and we therefore mainly focus on application-oriented papers, i.e. on investigations which are directly motivated by specific real-world problems (and/or experimental setups), tackled with existing BSS/ICA algorithms or original methods developed for these applications. This approach is especially used by industrial companies, or at least is most likely to eventually lead to industrial products. Hence the name of the "**Industrial** applications" session[3].

2. TRENDS IN BSS AND ICA APPLICATIONS

The application fields which emerge from the above description of the ICA'99 workshop seem natural when considered with respect to the first steps of the history of BSS and ICA.

More precisely, the first special session ever devoted to BSS in an international conference is presumably the one which took place in the frame of the "1995 International Symposium on Nonlinear Theory and its Applications" (NOLTA'95). This session mainly consisted of theoretical contributions, some of which were illustrated by simulations performed with synthetic data. However, this session also included a single application-driven paper[4] (i.e. [18], which appears in a somewhat extended form [19] in the IEICE special issue corresponding to that symposium). That paper deals with a topic related to radiocommunications, i.e. specifically with the use of a multi-antenna BSS-based system for identifying several simultaneously present items (e.g. people or objects) carrying radio-frequency (RF) tags. That system was developed by an industrial company, as an extension of a commercially available product which only applied to the situation when a single item was present at a time. Anticipating the subsequent developments to be reported below, it is worth mentioning that between the above-mentioned extremes, i.e. theoretical contributions and an industrial application, this session also included two papers in which the proposed algorithms were applied to already partly realistic signals. More precisely, the considered sources themselves were real signals. However, the mixed signals to be processed by BSS algorithms were artificially derived from these sources, by numerically computing linear instantaneous mixtures of them. They were therefore clearly unrealistic (i.e. instantaneous mixtures of audio signals [21] instead of the convolutive ones which are provided by actual microphones), or at least they were not provided by the sensors of an actual setup or justified by the description of the operation of such a setup (see the artificial instantaneous mixtures of images in [22]). Nevertheless, these investigations were a first step of importance towards the more refined works mentioned below.

The radiocommunication application field which was considered at NOLTA'95 was even more prominent [23][5], [24],[25] in the "Industrial applications" session organized in Sept. 1996 in the frame of a summer school on higher-order statistics, with main emphasis on BSS and ICA. This session, which is probably the first of this kind, also included a paper [26] reporting BSS analyses of signals measured in mechanical structures. These analyses concern: i) the monitoring of movements of dams, and ii) non-destructive control of the generators of nuclear power plants. Whereas the above papers emanated from industrial companies, other BSS/ICA applications developed by universities were presented in a poster session of this summer school. They cover the following fields:

- The separation of audio (speech and noise) signals [27][6]: although the considered mixtures of these sources were still artificially created, they now had a convolutive nature.
- Rotating machine monitoring [29], using artificial mixed signals derived from an experimental source.
- And, to a lower extent (because experimental results are not provided in this paper), seismic data analysis [30].

Only a few months later, a workshop on "Blind signal processing and [its] applications" was organized in

[3] This does not mean that the audio and biomedical application sessions are not "industrial", but only that their scopes are more focused and can therefore be detailed in their names.

[4] A second paper [20] in that session also involved real mixed signals, namely speech signals recorded in an anechoic chamber or a normal room. However, these signals were not processed by means of BSS/ICA algorithms, so that this paper is not considered as an application of the latter type of methods.

[5] For descriptions in English of the activities of this team, the reader may refer to [9] and references therein.

[6] For a related paper written in English, the reader may esp. refer to [28].

the frame of the "1996 Conference on Neural Information Processing Systems" (NIPS'96). This workshop mainly dealt with BSS and ICA. It included several presentations concerning the application of these methods to two fields which are still of importance in the frame of ICA'99, i.e: i) speech and audio signals (some of which were now recorded in completely real conditions), and ii) biomedical data (EEG and ERP).

In the above discussion, we only selected some of the (first) meetings focused on BSS and ICA, in order to illustrate the development of applications in these fields. Clearly, other such meetings were also organized, which cannot all be detailed here due to space limitations. Moreover, other applications were also described outside such focused meetings (for instance, the early paper [1] cited above already refers to satellite communications). But it is believed that a more complete review of all the application papers published in these domains would confirm (and refine) the trends that appeared above. This shows a coherent evolution of the applications of BSS and ICA, with major application fields progressively appearing. The emphasis is especially put on three of them in the ICA'99 workshop. Others are growing, such as rotating machine monitoring [13],[14],[29] or image processing, which already gave rise to various types of investigations, e.g. [16],[22],[31]-[35] And, hopefully, many other application domains are still to appear !

3. FROM ALGORITHMS TO APPLICATIONS AND HARDWARE

The development of a specific field inside the area of signal processing and data analysis contains three aspects. Of course, the first step consists in developing **processing methods** for performing the functions of interest in the considered field. Whereas these methods are first only tested on toy problems, the subsequent emergence of **real-world applications** of these methods is an indication that the considered field is becoming more mature. That is the topic that we discussed up to this point in this paper. But once the usefulness of these methods has thus been shown, a need for efficient implementation often appears. This gives rise to the emergence of a third type of activities in the considered field, i.e. the development of **hardware structures** dedicated to the considered algorithms. All three subfields then keep on evolving, taking advantage of each other: advanced algorithms clearly open new ways for applications and implementations, but a feedback phenomenon also exists, as new algorithms emerge from practical problems and required new functions in applications as well as constraints met in hardware structures.

If only to give a single recent example, this phenomenon occured in the field of artificial neural networks, which by the way has a significant overlap with BSS and ICA. Specifically, for a description of the cross-fertilization which thus took place in a particular industrial company between algorithmic, application and hardware developments concerning neural networks, the reader may e.g. refer to [36],[37] (or [38]).

Such an evolution is expected to occur in the field of BSS and ICA. Especially, optimized hardware implementations will be needed when tackling applications which involve a large number of sensors and which therefore require a high processing power. In fact, some labs already designed "preliminary" BSS hardware structures, i.e. test circuits (as opposed to the commercial chips which are already available e.g. in the above-mentioned general field of neural networks). The first BSS test chips were related to one of the very first (neural) methods, i.e. the Hérault-Jutten algorithm [2]-[4]. They were based on hybrid [39]-[40] or integrated [41]-[43] analog circuits. Modified versions of this algorithm were then also integrated [44]. The current activity in this field is reflected in the ICA'99 workshop by a paper [45] which reports investigations on analog and digital implementations of a more advanced, i.e. equivariant, algorithm. All the implementations listed above were focused on the BSS processing module itself[7]. However, the overall BSS problem also consists of another major aspect, i.e. the acquisition of the mixed signals by a set of sensors (whose nature is fixed by the target application). This problem is therefore particularly well-suited to a microsystem approach, in which the sensors would be integrated on the same chip as the BSS module and all subsequent processing modules, in order to obtain a complete compact low-cost system dedicated to the considered application. Microsystem approaches, which are currently receiving a lot of attention, are therefore likely to have an increasing impact on the hardware side of the BSS/ICA field in the coming years.

So, if trying to summarize all this discussion by a single statement, we would insist again on the importance of the development of specific applications for the whole BSS/ICA field, or in other words, we would predict that this field will be fertilized by the available sources ... which seems quite natural[8] !

[7] [45] also includes a few comments about the topic addressed hereafter.

[8] At least from an agricultural point of view ...

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