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Blind Source Separation of Instantaneous Mixtures

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***Abstract*—Blind source separation of images and voice signals is a well known and well studied subject. Solutions for this problem have various applications, such as separation of voices of multiple speakers in the same room, denoising, separation of reflections superimposed on images, and more.**

Classical time/position invariant Blind Source Separation is usually solved using Independent Component Analysis (ICA), which attempts to find statistically independent signals as a linear combination of the mixed signals, or by using Sparse Component Analysis (SCA) that estimates the mixing matrix by analyzing the geometry of the problem and uses scatter plots of the mixed signals to estimate co-linear centroids of the scattered data, where each centroid corresponds to a column of the mixing matrix.

Most of the studies in the field assume time/position invariant signal combinations, although many real life problems are not such. Recently, in his PhD thesis, Ran Kaftory has proposed an extension of the SCA method to solve multiple families of the time/position varying problems. He has shown that for instantaneous time/position varying mixtures, the problem of lines estimation transforms to estimation of nonlinear curves.

In this work we explore the separation of instantaneous time/position varying mixtures for which the parametric structure of the mixtures family is known apriori .We show that the geometric approach can also be viewed as Maximum Likelihood (ML) problem, when sparsification is applied to the mixed signals. We propose a multi-staged SCA algorithm for separation of time/position invariant mixtures and extend the solution to a subset of time/position varying mixtures where the reconstruction is performed by curve fitting techniques and nearest neighbor clustering.

In addition to the geometric approach, we extend the well-known technique of ICA by the ML approach, to the case of time/position varying instantaneous mixtures. We show that ML approach to the time/position varying separation problem can be developed from an information theoretic perspective as a joint Entropy minimization of the unmixed signals. We prove that although the problem is non-convex, and may require non-linear optimization techniques to solve, under certain conditions the correct signals separation constitutes a global maximum of the ML optimization problem.

We conclude by showing that the ML approach provides promising results, but due to the non-linear nature of the problem, its optimization is challenging and SCA-based approaches can be used as a complimentary technique to circumvent some of the difficulties originating from the non-linearities of the problem.

I. Introduction

Blind source separation (BSS) [12] has attracted a great deal of attention in recent decades. BSS deals with the decomposition of given mixtures of signals/images onto the original signals. This problem arises in real life applications in communication systems, voice processing, photography and filmography. The classical formulation of the problem is best illustrated by the Cocktail Party problem [12]. At Cocktail Party, a human brain is capable of separating single speaker from many and from additional background noises. Although we believe that human brain relies on additional information, such as visual information and prediction of words from the context, it is still possible to reconstruct the voice signal by using only multiple microphones/sensors which provide sufficient information for estimating the signals up to some error.

In this work we present results for both time/position varying and invariant mixtures but most of the focus of this work is on the BSS of time/position varying mixtures. The classical BSS approach assumes that the mixtures and weights do not change with time/position, however in real life application this assumption is almost never true. Even a simple Cocktail Party problem as described above is not time invariant due to the movement of the people and changes of the environment. Applications assuming that mixtures vary with time/position are much more complicated than those which assume the time/position invariance, due to the fact that the space of the reconstruction contains many degrees of freedom. In general, we believe that it is impossible to reconstruct signals from time/position varying mixtures without additional information or additional assumptions about the mixture families. In this work we assume that the mixing family is known up to several parameters. This assumption allows us to develop techniques for searching the optimal reconstruction parameters.

A. Problem Definition

1) Instantaneous Time/Position invariant BSS: Time/Position invariant BSS (TPIBSS) separation can be described as a Multiple Input-Multiple Output (MIMO) system, where the inputs are linearly mixed signals and the outputs are the reconstructions of the unmixed signals. The TPIBSS problem is a well studied problem and various solutions have been developed for the problem in the past decades. In many studies, the problem is solved using Maximum Likelihood (ML) or similar approach [2], [6], [10], [13], while other use geometric approach based on Sparse Component Analysis [4],[5],[25].

A formal definition of this problem assumes that there exists