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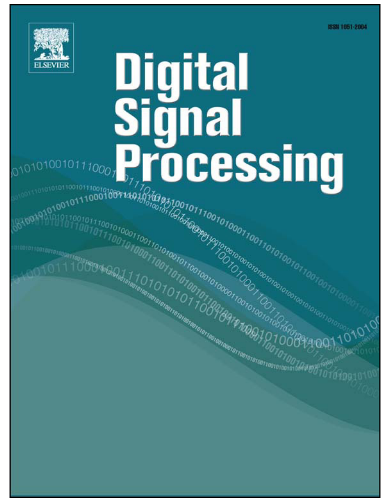

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Blind quantum source separation: quantum-processing qubit uncoupling systems based on disentanglement

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Abstract

Blind Quantum Source Separation (BQSS) deals with multi-qubit states, called "mixed states", obtained by applying an unknown "mixing function" (which typically corresponds to undesired coupling, e.g. between qubits implemented as close electron spins 1/2) to unknown multi-qubit "source states", which are product states (and pure in the simplest case, considered in this paper). Some other properties are also possibly requested from these source states and/or mixing function. Using mixed states, BQSS systems aim at restoring (the information contained in) source states, during the second phase of their operation ("inversion phase"). To this end, they estimate the unmixing function (inverse of mixing function), during the first phase of their operation ("adaptation phase"). Most previously reported BQSS systems first convert mixed states into classical-form data, that they then process with classical means. Besides, they estimate the unmixing function by using statistical methods related to classical Independent Component Analysis. On the contrary, the new BQSS systems proposed here use only quantum-form data and quantum processing in the inversion phase, and they use classical-form data during the adaptation phase only. Moreover, their unmixing function estimation methods are essentially based on using unentangled source states during that phase. They mainly consist of disentangling the output quantum state of the separating system (for a few source states). Afterwards, they can also restore entangled source states. They yield major improvements over previous systems, concerning restored source parameters, associated indeterminacies and approximations, number of source states required for adaptation, numbers of source state preparations in adaptation and inversion phases. Numerical tests confirm that they accurately restore quantum source states.

Keywords: separation and restoration of quantum states, entanglement, disentanglement, blind or unsupervised quantum processing, control of quantum adaptive system, cylindrical-symmetry Heisenberg coupling

1. Introduction

Blind (or unsupervised) Source Separation (BSS) is a generic classical (i.e. non-quantum) signal processing problem, which may be briefly defined as the estimation of a set of source signals which have unknown values but some known properties, using known values of a set of mixed signals which result from the application of an (almost) unknown mixing function to these source signals. Depending on the considered source signal properties and/or type of mixing function, various classes of BSS methods, including Independent Component Analysis (ICA), have been developed and are e.g. detailed in the books [7],[9],[14] [31],[35] or encyclopedia [23]. These publications also present quite varied applications of BSS methods. Such applications are described in Appendix A.1 and Appendix A.2.

Beyond the above diversity of classical signals which lead to BSS problems, one may anticipate that "quantum signals" will require quantum extensions of BSS methods, as the field of Quantum Information Processing [3],[26],[38],[40],[47] keeps on extending in the coming years. Quantum signals are especially defined in terms of quantum bit (i.e. qubit) states, with qubits e.g. physically implemented as electron spins. Therefore, quantum BSS methods are expected to involve "mixtures" of qubit states, where the term "mixtures" is used in the above classical BSS sense[1], i.e. combinations of these states, e.g. due to electron spin coupling. Such coupling may occur in future quantum computers, when qubit registers involve electron spins situated close to one another.

This led us to introduce the field of Quantum Source Separation (QSS), and especially its Blind version[2] (BQSS), first proposed in [11] and then especially detailed in [17] and [21] (see Appendix A.3 and Appendix A.4 for applications of BQSS). The BQSS problem thus consists of restoring the information contained in individual quantum source states which have unknown values but some known properties, using known values of the mixtures of these source states which result from their *undesired*[3] coupling, when the coupling operator is unknown (or only partly known). One may think of restoring the source states by transferring their available mixtures through the inverse of the coupling operator. However, this cannot be straightforwardly performed, because this operator is *unknown*. This

[1] We are not considering quantum states which are statistical mixtures.

[2] See [17] for more details about its non-blind version, which is not considered in the present paper.

[3] On the contrary, a two-qubit gate using liquid NMR *takes advantage* [46] of the scalar coupling.