A Robust ICA-Based Adaptive Filter Algorithm for System Identification Using Stochastic Information Gradient

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Abstract. This paper proposes a new adaptive filter algorithm for system identification by using an independent component analysis (ICA) technique, which separates the signal from noisy observation under the assumption that the signal and noise are independent. We first introduce an augmented state-space expression of the observed signal, representing the problem in terms of ICA. By using a nonparametric Parzen window density estimator and the stochastic information gradient, we derive an adaptive algorithm to separate the noise from the signal. The computational complexity of the proposed algorithm is compared with that of the standard NLMS algorithm. The local convergence is analyzed. Due to the additive noise is also on-line estimated during the iteration, the proposed algorithm shows excellent robustness. It can directly be applied to an acoustic echo canceller without any double-talk detector. Some simulation results are carried out to show the superiority of our ICA method to the conventional NLMS algorithm.

1 Introduction

Adaptive filter techniques have been applied to many system identification problems in communications and noise control [1][2]. The two most popular algorithms, i.e. LMS and RLS, are both based on the idea that the effect of additive observation noise is to be suppressed in the least square sense. But if the noise is non-Gaussian, the performances of the above algorithms degrade significantly. The other class of non-linear algorithms has been derived based on the robust estimation theory [3], but these algorithms are a little bit heuristic.

On the other hand, in recent years, independent component analysis (ICA) has been attracting much attention in many fields such as signal processing and machine learning [4]. However, in the adaptive filter area, there have been only a few papers which try to derive adaptive algorithms from the viewpoint of ICA. The authors in [5] tried to formulate the conventional system identification problem in the ICA context, but the proposed algorithm is nothing but the QR type RLS algorithm. In [6] a truly ICA type algorithm based on minimizing the mutual information has been derived for identification of multivariate autoregressive models. In [7], by combining the approaches in [5] and [6], we proposed...
a new adaptive algorithm for system identification using the technique of ICA. We try not to suppress the noise in the least mean square sense but to maximize the independence between the signal part and the noise. The usual mutual information is used to measure the independence and a nonlinear function concerning the probability density function (pdf) of the additive noise signal appears in the algorithm. Since this is unknown, it is fixed to some typical one, say, the hyperbolic tangent function as in many papers on the usual ICA. But this fixed function does not always fit to the changing situation and it is highly desirable to estimate the pdf directly by using some adaptive procedure. In this paper, on the basis of the framework in [7] we use the nonparametric Parzen window density estimator [8] and the stochastic information gradient (SIG) [9] to derive a new adaptive gradient descent algorithm for system identification. The organization of this paper is as follows: In Section 2 we introduce an augmented linear model representing the problem in the framework of ICA, and then propose a new adaptive algorithm in Section 3 by using the ICA technique. The computational complexity of the proposed algorithm is also compared with that of the standard NLMS algorithm. In Section 4, the local stability of the algorithm is analyzed and a step size condition is also derived. Section 5 shows that the new ICA-based method has an excellent robustness and can directly be applied to the acoustic echo canceller without the usage of double talk detector (DTD). Finally, some numerical simulations are demonstrated to show the superiority of our ICA-based method to the conventional NLMS algorithm.

2 Problem Formulation

We consider the problem of identifying a linear system described by

\[ y(n) = h^T x(n), \tag{1} \]

where \( h = [h_0 \ h_1 \cdots h_{m-1}]^T, \ \ x(n) = [x(n) \ x(n-1) \cdots x(n-m+1)]^T. \)  
\( x(n) \) is the zero mean input signal. The measurement of the system output \( y(n) \) is corrupted by additive noise \( e(n), \) that is, \( d(n) = y(n) + e(n). \)  
We assume the noise \( e(n) \) is zero mean and statistically independent with the system input \( x(n). \)  
Statistical independence is a much stronger condition than uncorrelatedness. As a result, statistics of order higher than the second has to be considered for non-Gaussian signals.

We now introduce the following augmented linear model to formulate the problem of system identification in the frame work of ICA:

\[
\begin{bmatrix}
    x(n) \\
    d(n)
\end{bmatrix} =
\begin{bmatrix}
    I & 0 \\
    h^T & 1
\end{bmatrix}
\begin{bmatrix}
    x(n) \\
    e(n)
\end{bmatrix},
\tag{2}
\]

where \( I \) denotes the identity matrix. The noise signal \( e(n), \) which is assumed to be independent of the input signal \( x(n), \) is expected to be separated from the observation signal. So we may consider the system identification problem as an