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Research Letter

Improved Parameter Estimation for First-Order Markov Process

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This correspondence presents a linear transformation, which is used to estimate correlation coefficient of first-order Markov process. It outperforms zero-forcing (ZF), minimum mean-squared error (MMSE), and whitened least-squares (WTLSs) estimators by controlling output noise variance at the cost of increased computational complexity.

1. Introduction

Let us consider a linear multi-input multioutput model with an unknown $N \times 1$ parameter vector $\vec{x}(n) = [a_1 a_2 \cdots a_N]^T$, such that

$$\vec{y} = H\vec{x} + \vec{v}, \tag{1}$$

where, $\vec{y}(n) = [h(n)h(n-1)\cdots h(n-M+1)]^T$ is $M \times 1$ output vector,

$$H(n) = \begin{bmatrix} h(n-1) & h(n-2) & \cdots & h(n-N) \\ h(n-2) & h(n-3) & \cdots & h(n-N-1) \\ h(n-M) & h(n-M-1) & \cdots & h(n-N-M+1) \end{bmatrix} \tag{2}$$

is $M \times N$ complex matrix, and $\vec{v}(n) = [v(n)v(n-1)\cdots v(n-M+1)]^T$ is white Gaussian process noise $M \times 1$ vector with zero-mean and covariance matrix $\sigma_v^2 I_M$, where I_M is $M \times M$ identity matrix. The estimated unknown parameter vector may be defined as $\hat{x} = T\vec{y}$, where "T" is linear transformation involving pseudoinverse. The application of ZF linear transformation $T_{\text{ZF}} = (H^H H)^{-1} H^H$ to $\vec{y}$ results in nonwhite noise with covariance matrix $C_{\text{ZF}} = \sigma_v^2 (H^H H)^{-1}$. On the other hand, MMSE linear transformation $T_{\text{MMSE}} = (H^H H + \sigma_v^2 I_N)^{-1} H^H$ alleviates output noise variance by finding the optimum balance between data detection and noise reduction [1]. However, the modification of least squares estimation is based on the concept of MMSE whitening; that is, WTLS performs well at low to moderate signal-to-noise ratios by using linear transformation $T_{\text{WTLS}} = B(H^H H)^{-1/2} H^H$ [2], where $B = \text{diag}[\beta_1, \beta_2, \ldots, \beta_N]$ with $\beta = \beta_1 = \beta_2 = \cdots = \beta_N = \text{Tr}\{(H^H H)^{1/2}\}/\text{Tr}\{H^H H\}$. It follows that

$$\hat{x}_{\text{WTLS}} = B\left(H^H H\right)^{1/2} \vec{x} + B\left(H^H H\right)^{-1/2} H^H \vec{v}. \tag{3}$$

Substitution of the unique QR-decomposition $H = QD\overline{M}$ in (3) leads to

$$\hat{x}_{\text{WTLS}} = BD\overline{M}\vec{x} + BQ^H \vec{v} \tag{4}$$

where, $Q = [q_1, q_2, \ldots, q_N]$ is an $M \times N$ matrix with orthonormal columns, D is an $N \times N$ real diagonal matrix whose diagonal elements are positive, and $\overline{M}$ is an $N \times N$ upper triangular matrix with ones on the diagonal (on contrary to [3]). Incorporation of $BD = I_N$ in (4) yields $\hat{x}_{\text{WTLS}} = \overline{M}\vec{x} + D^{-1} Q^H \vec{v}$, where $D^{-1}Q^H$ is referred to as noise whitening-matched filter [4].

2. AR(1) Parameter Estimation

In the presented exposition, the posited linear transformation is $T_{\text{MZF}} = \overline{M}(H^H H)^{-1} H^H$. Consequently,

$$\hat{x}_{\text{MZF}} = T_{\text{MZF}} \vec{y} = \overline{M}\vec{x} + \overline{M}\left(H^H H\right)^{-1} H^H \vec{v} \tag{5}$$

with noise covariance matrix $C_{\text{MZF}} = \sigma_v^2 \overline{M}(H^H H)^{-1} \overline{M}^H$. This transformation also performs noise whitening. It is

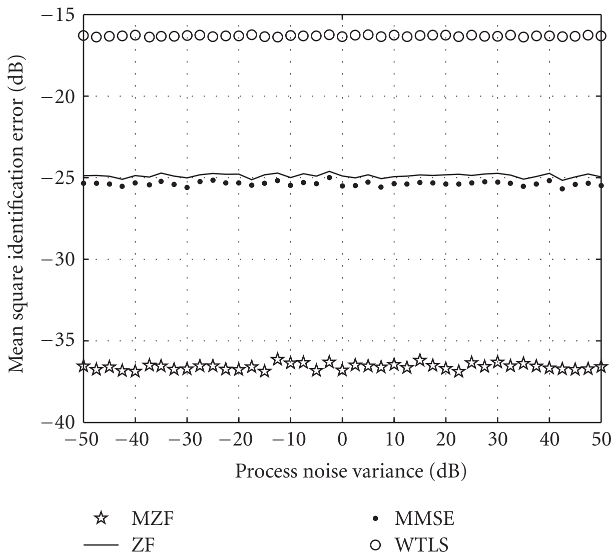

FIGURE 1: MSIE versus process noise variance (σ_v^2 dB).

apparent that output noise variance is controlled and reduced, since $0 \leq m_{i,j} < 1$ for $i \neq j$ (i.e., ith row and jth column element of matrix $\overline{M}$). For AR(1) correlation coefficient (a_1) estimation, the unknown parameter vector $\vec{x}$ in (1) and (5) is replaced by $\overline{x} = [a_1 \Delta a_2 \Delta a_3 \cdots \Delta a_N]^T$ with leakage coefficients $\Delta a_j \rightarrow 0$. Thus, the estimated parametric value is

$$\hat{x}_{\text{MZF},1} = \hat{a}_1 = a_1 + \lim_{\Delta a_j \rightarrow 0} \sum_{j=2}^{N} m_{1,j} \Delta a_j + v_{\text{MZF},1} \qquad (6)$$

with $0 \leq m_{1,j} < 1$ for $j \neq 1$. For parameter values $a_1 = 0.95$ (true correlation coefficients) and $\Delta a_2 = \Delta a_3 = \Delta a_4 \approx 0.0001$ (assumed), the simulation results depicted in Figure 1 demonstrate that the proposed technique outperforms other aforementioned linear transformations. However under similar conditions, the value of β is found to be high in case of WTLS transform, which in turn increases the output noise variance.

3. Conclusions

The presented linear transformation based on a typical QR-decomposition (i.e., $QD\overline{M}$) reduces output noise, which is utilized for the efficient estimation of correlation coefficient in first-order Markov process.

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EURASIP Journal on Wireless Communications and Networking

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Cooperative communication is an overwhelming research topic in wireless networks. The notion of cooperative communication is to enable transmit and receive cooperation at user level by exploiting the broadcast nature of wireless radio waves so that the overall system performance including power efficiency and communication reliability can be improved. However, due to the half-duplex constraint in practical systems, cooperative communication suffers from loss in spectral efficiency. Network coding has recently demonstrated significant potential for improving network throughput. Its principle is to allow an intermediate network node to mix the data received from multiple links for subsequent transmission. Applying the principle of network coding to wireless cooperative networks for spectral efficiency improvement has recently received tremendous attention from the research community. *Physical-layer network coding* (PLNC) is now known as a set of signal processing techniques combining channel coding, signal detection, and network coding in various relay-based communication scenarios, such as two-way communication, multiple access, multicasting, and broadcasting. To better exploit this new technique and promote its applications, many technical issues remain to be studied, varying from fundamental performance limits to practical implementation aspects. The aim of this special issue is to consolidate the latest research advances in physical-layer network coding in wireless cooperative networks. We are seeking new and original contributions addressing various aspects of PLNC. Topics of interest include, but not limited to:

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In recent years, the mathematical field of random matrix theory (RMT) has emerged as an extremely powerful tool for a variety of signal processing applications. Recent advances, both in the areas of exact (finite-dimensional) and asymptotic (large-dimensional) RMTs, have received strong interest from amongst the signal processing community and have been instrumental for a number of recent breakthroughs. For example, advances in RMT techniques have paved the way for the design of powerful multiantenna and multiuser signal processing modules which are currently revolutionizing the field of wireless communications; they have led to fundamental insights into the information-theoretic limits (achievable by any signal processing strategy) in multidimensional wireless channels; they have pushed forward the development of advanced synthetic aperture radar (SAR) imaging techniques; they have provided the key ingredient for designing powerful new detection and estimation techniques in array signal processing.

This Special Issue aims to bring together state-of-the-art research contributions that address open problems in signal processing using RMT methods. While papers that are primarily of mathematical interest will be considered, the main focus is on applications of these techniques to real-world signal processing problems. Potential topics include (but are not limited to) the following areas:

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Recently, there has been a growing interest in femtocell networks both in academia and industry. They offer significant advantages for next-generation broadband wireless communication systems. For example, they eliminate the dead-spots in a macrocellular network. Moreover, due to short communication distances (on the order of tens of meters), they offer significantly better signal qualities compared to the current cellular networks. This makes high-quality voice communications and high data rate multimedia type of applications possible in indoor environments.

However, this new type of technology also comes with its own challenges, and there are significant technical problems that need to be addressed for successful deployment and operation of these networks. Standardization efforts related to femtocell networks in 3GPP (e.g., under TSG-RAN Working Group 4 and LTE-Advanced) and IEEE (e.g., under IEEE 802.16m) are already underway.

The goal of this special issue is to solicit high-quality unpublished research papers on design, evaluation, and performance analysis of femtocell networks. Suitable topics include but are not limited to the following:

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