



Performance analysis of the recursive parameter estimation algorithms for multivariable Box–Jenkins systems[☆]

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Abstract

Two auxiliary model based recursive identification algorithms, a generalized extended stochastic gradient algorithm and a recursive generalized extended least squares algorithm, are developed for multivariable Box–Jenkins systems. The basic idea is to use the auxiliary models to estimate the unknown noise-free outputs of the system and to replace the unmeasurable terms in the information vectors with their estimates. We prove that the estimation errors given by the proposed algorithms converge to zero under the persistent excitation condition. Finally, an example is provided to show the effectiveness of the proposed algorithms. © 2014 The Franklin Institute. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Parameter estimation has wide applications in system identification [1–4], signal processing [5,6], controller design [7–9], state estimation and filtering [10,11] and Adaptive fault-tolerant control [12–15], etc. Existing estimation methods can be roughly divided into three categories: the one-shot

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algorithms [16], the recursive methods [17–19] and the iterative methods [20–22]. The recursive methods can be used for online identification and may reduce the storage requirements, attracting considerable attention for decades. Recently, Alenany and Shang proposed a recursive subspace method for time-varying systems by incorporating prior information to improve the model accuracy [23]; Yu et al. developed a recursive algorithm for identifying Hammerstein–Wiener system with a dead-zone nonlinearity input block [24]; Wang et al. presented a least squares algorithm for an input nonlinear system with a dynamic subspace state space model [25] and developed a recursive least squares algorithm for Hammerstein nonlinear systems based on the data filtering technique [26].

Multivariable systems, i.e., multi-input multi-output systems, widely exist in chemical engineering and mechanical engineering. Various methods, such as the expectation–maximization algorithms [27,28], the subspace methods [29,30] and the stochastic gradient methods [31], have been reported for multivariable systems in the literature. For multivariable systems with colored noise, Wang et al. presented a hierarchical identification algorithm by decomposing a multivariable system into several subsystems [32].

The stochastic process theory and the martingale convergence theory are the main tools for analyzing the convergence of the recursive identification algorithms [33]. On the convergence of multivariable systems, Liu and Ding studied the convergence of recursive least squares methods for multivariable ARX-like systems and multivariable moving average systems under the conditions that the observed noise has zero mean and finite second-order variance [34]; Ding proposed a coupled least squares algorithm for multivariable systems to avoid computing the matrix inversion and studied its convergence [35]; Ding and Gu discussed the performance of the auxiliary model based stochastic gradient (recursive least squares) algorithm for time-delay systems by transforming the state-space model into the linear regression form [36,37]. On the basis of the work in [36,37], this paper presents an auxiliary model recursive generalized extended least squares (AM-RGELS) algorithm and an auxiliary model generalized extended stochastic gradient (AM-GESG) algorithm for multivariable Box–Jenkins systems, and studies their convergence.

Briefly, this paper is organized as follows. Section 2 derives the identification model for multivariable Box–Jenkins systems. Sections 3 and 4 present an AM-GESG algorithm and an AM-RGELS algorithm and analyze their convergence. Section 5 provides an illustrative example to show the effectiveness of the proposed algorithms. Finally, concluding remarks are given in Section 6.

2. System description and identification model

Consider the following multivariable Box–Jenkins systems:

$$\mathbf{y}(t) = \mathbf{A}^{-1}(z)\mathbf{B}(z)\mathbf{u}(t) + \mathbf{C}^{-1}(z)\mathbf{D}(z)\mathbf{v}(t), \quad (1)$$

where $\mathbf{y}(t) = [y_1(t), y_2(t), \dots, y_m(t)]^T \in \mathbb{R}^m$ is the system output vector, $\mathbf{u}(t) = [u_1(t), u_2(t), \dots, u_r(t)]^T \in \mathbb{R}^r$ is the system input vector, $\mathbf{v}(t) = [v_1(t), v_2(t), \dots, v_m(t)]^T \in \mathbb{R}^m$ is a white noise vector. $\mathbf{A}(z)$, $\mathbf{B}(z)$, $\mathbf{C}(z)$ and $\mathbf{D}(z)$ are the polynomial matrices in the unit backward shift operator z^{-1} [$z^{-1}\mathbf{y}(t) = \mathbf{y}(t-1)$],

$$\mathbf{A}(z) := \mathbf{I} + \mathbf{A}_1 z^{-1} + \mathbf{A}_2 z^{-2} + \dots + \mathbf{A}_{n_a} z^{-n_a} \in \mathbb{R}^{m \times m},$$

$$\mathbf{B}(z) := \mathbf{B}_1 z^{-1} + \mathbf{B}_2 z^{-2} + \dots + \mathbf{B}_{n_b} z^{-n_b} \in \mathbb{R}^{m \times r},$$

$$\mathbf{C}(z) := \mathbf{I} + \mathbf{C}_1 z^{-1} + \mathbf{C}_2 z^{-2} + \dots + \mathbf{C}_{n_c} z^{-n_c} \in \mathbb{R}^{m \times m},$$

$$\mathbf{D}(z) := \mathbf{I} + \mathbf{D}_1 z^{-1} + \mathbf{D}_2 z^{-2} + \dots + \mathbf{D}_{n_d} z^{-n_d} \in \mathbb{R}^{m \times m},$$

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