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Recursive and iterative least squares parameter estimation algorithms for observability canonical state space systems

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Abstract

This paper considers parameter identification problems for the observability canonical state space systems, and a state observer based recursive least squares identification algorithm and a Kalman filter based least squares iterative identification algorithm are proposed for estimating the system parameters and states. A numerical example is provided to confirm the effectiveness of the proposed algorithms.

1. Introduction

System identification has commanded scientific attention in different areas and many identification methods were born for decades [1–3], e.g., the recursive algorithms [4,5], the iterative algorithms [6–8] and the multi-innovation stochastic gradient algorithms [9]. Besides, the recursive algorithm or the iterative algorithm are often adopted for solving matrix equations [10–12]. The state observer algorithm and the Kalman filter algorithm are both typical recursive algorithms for state estimation that use the available input–output data to estimate the states of the dynamic system [13–16]. State estimation is necessary for designing controllers based on state feedback [17–19].

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The least squares method is effective for system identification [20–22]. In this literature, there exist many parameter estimation methods for system identification, e.g., the recursive least squares identification methods [23,24], the iterative based least squares identification methods [26] and the auxiliary model based least squares identification methods [25]. Recently, Zhang derived a recursive least squares identification algorithm for multi-input single-output state space systems based on the bias compensation technique [27]. Hu et al. presented a decomposition based least squares estimation algorithm for feedback nonlinear systems [28]. Ahn et al. proposed an estimation method for a nonlinear state space model on minimizing the conditional least squares [29].

State space models can describe the physical systems and have been widely used for control schemes [30,31], system modeling [32], signal filtering [33] and parameter estimation [34,35]. However, the parameter identification becomes more difficult because the state space models include not only the unknown parameter matrices or vectors, but also the unknown states [36–38]. In this field, Ding et al. proposed a hierarchical identification method for the lifted state space model of general dual-rate systems [39] and a new least squares parameter estimation algorithm for canonical state space systems [40]. Liu et al. presented an efficient hierarchical identification method for general dual-rate sampled-data systems [41]. Gu et al. proposed a state estimation based recursive least squares parameter identification algorithm for state space models with d-step state-delay [42]. This paper focuses on the modeling and parameter identification problem for observability canonical state space systems and proposes the state and parameter estimation algorithms in combination with the least squares principle, the recursive and the iterative algorithm and the hierarchical identification principle.

Briefly, this paper is organized as follows. Section 2 presents the identification model for the observability canonical state space systems. Sections 3 and 4 derive the state observer based recursive least squares identification algorithm and the Kalman filter based least squares iterative identification algorithm. Section 5 provides an example to verify the effectiveness of the proposed algorithms. Finally, concluding remarks are given in Section 6.

2. The identification model for the state space systems

Let us define some notation. "$A=:X$" or "$X:=A$" stands for "A is defined as X". Let z denote a unit forward shift operator with $z\boldsymbol{x}(t)=\boldsymbol{x}(t+1)$ and $z^{-1}\boldsymbol{x}(t)=\boldsymbol{x}(t-1)$.

Recently, a Kalman filter based gradient iterative algorithm and an observer-based multi-innovation stochastic gradient algorithm have been presented for the state space observer canonical state space systems [43]. This paper considers the recursive and iterative least squares parameter estimation problems of the following observability canonical state space system:

$$\boldsymbol{x}(t+1)=\boldsymbol{A}\boldsymbol{x}(t)+\boldsymbol{b}u(t), \tag{1}$$

$$y(t)=\boldsymbol{c}\boldsymbol{x}(t)+v(t), \tag{2}$$

where $\boldsymbol{x}(t):=[x_1(t),x_2(t),\ldots,x_n(t)]^{\mathrm{T}}\in\mathbb{R}^n$ is the state vector, $u(t)\in\mathbb{R}$ is the system input, $y(t)\in\mathbb{R}$ is the system output, $v(t)\in\mathbb{R}$ is random noise with zero mean, $\boldsymbol{A}\in\mathbb{R}^{n\times n}$, $\boldsymbol{b}\in\mathbb{R}^n$ and $\boldsymbol{c}\in\mathbb{R}^{1\times n}$ are