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Combined state and parameter estimation for a bilinear state space system with moving average noise☆

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Abstract

This paper considers the identification problem of bilinear systems with measurement noise in the form of the moving average model. In particular, we present an interactive estimation algorithm for unmeasurable states and parameters based on the hierarchical identification principle. For unknown states, we formulate a novel bilinear state observer from input-output measurements using the Kalman filter. Then a bilinear state observer based multi-innovation extended stochastic gradient (BSO-MI-ESG) algorithm is proposed to estimate the unknown system parameters. A linear filter is utilized to improve the parameter estimation accuracy and a filtering based BSO-MI-ESG algorithm is presented using the data filtering technique. In the numerical example, we illustrate the effectiveness of the proposed identification methods.

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1. Introduction

Linear systems have been studied extensively to describe physical phenomena for their analytical simplicity and have achieved a fairly well development. With the development of modern control theory, the intrinsic limits of linear models appear increasingly evident, especially in the complex industrial processes modeling and analyzing [1]. Consequently, the research of nonlinear systems has attracted much attention to overcome the analytical difficulties. Bilinear systems are recognized as a universal approximator for many nonlinear systems [2,3]. This property makes bilinear systems a bridge between linear and nonlinear systems for their applicative interest and intrinsic simplicity [4]. Due to this simplicity in model structures, they are involved in a wide range of applications in many areas such as nuclear engineering, chemical engineering, and biology engineering [5].

For decades, the parameter estimation methods have received much attention [6–8], including the subspace method [9] and the hierarchical identification methods [10,11]. System identification is the basis of system control [12–14]. The system identification of bilinear systems has been studied for a long time [15–17]. Karanam et al. discussed a method of identifying continuous-time, time-variant bilinear systems that relies on the approximate input and output signals using a finite orthonormal expansion formed by Walsh functions [18]. Liu and Shih and Wang et al. solved the parameter estimation problem for bilinear systems via Chebyshev polynomials and generalized orthogonal polynomials, respectively [19,20]. Karray and Dwyer adopted the bilinear approximation method to model nonlinear systems for parameter identification [21]. Dai and Sinha proposed a robust method that minimized a robust criterion to identify bilinear systems utilizing the block-functions [22]. Verdult and Verhaegen, utilized a least squares support vector machine for bilinear subspace identification to balance the bias and variance errors [23]. Hizir et al. presented an observer/Kalman filter identification algorithm of discrete-time, time-invariant bilinear systems by transforming the bilinear model into an equivalent linear model [24]. Li et al. transformed a special bilinear state space model into the transfer function by eliminating the state variables in the model, then presented the iterative parameter estimation algorithms based on the hierarchical identification [25].

State estimation is widely applied in signal processing [26–28]. In the existing literature about state estimation [29], Ma et al. adopted a modified Kalman filter to estimate the unknown states of the multivariate Hammerstein systems on basis of the hierarchical recursive least squares parameter identification algorithm [30]. Recently, the minimal-order state observers were discussed for bilinear systems and the necessary conditions were found [31,32]. Phan et al. designed an optimal bilinear state observer based on the extension of the observer/Kalman filter for bilinear systems, and established the gains of the proposed observer with the interaction matrices [33]. Zhang et al. discussed recursive parameter identification of the dynamical models for bilinear state space systems based on the open-loop observer [34]. Wang and Ding extended the Kalman filter from linear systems to input nonlinear state space systems to obtain the system states using the identified parameters based on the hierarchical identification principle [35]. The data filtering technique has been proved to be effective both in parameter identification [36,37] and state estimation [38,39]. Liu et al. presented a data filtering algorithm for a dual-rate state space model with time-delay [40]. They designed a linear filter to filter the input and output signals, leading to a noise model and a filtered