Available online at www.sciencedirect.com

ScienceDirect

Journal of the Franklin Institute 354 (2017) 593–609

Journal of The Franklin Institute

www.elsevier.com/locate/jfranklin

Filtering based parameter estimation for observer canonical state space systems with colored noise ☆

Xuehai Wang[a,b], Feng Ding[b,c,*], Ahmed Alsaedi[c], Tasawar Hayat[c,d]

[a]College of Mathematics and Information Science, Xinyang Normal University, Xinyang 464000, PR China
[b]Key Laboratory of Advanced Process Control for Light Industry (Ministry of Education), Internet of Thins Engineering, Jiangnan University, Wuxi 214122, PR China
[c]Nonlinear Analysis and Applied Mathematics (NAAM) Research Group, Department of Mathematics, King Abdulaziz University, Jeddah 21589, Saudi Arabia
[d]Department of Mathematics, Quaid-I-Azam University, Islamabad 44000, Pakistan

Received 29 December 2015; received in revised form 18 June 2016; accepted 21 October 2016
Available online 27 October 2016

Abstract

This paper surveys the identification of observer canonical state space systems affected by colored noise. By means of the filtering technique, a filtering based recursive generalized extended least squares algorithm is proposed for enhancing the parameter identification accuracy. To ease the computational burden, the filtered regressive model is separated into two fictitious sub-models, and then a filtering based two-stage recursive generalized extended least squares algorithm is developed on the basis of the hierarchical identification. The stochastic martingale theory is applied to analyze the convergence of the proposed algorithms. An experimental example is provided to validate the proposed algorithms.

☆This work was supported by the National Natural Science Foundation of China (No. 61273194) and the Graduate Research Innovation Program of Jiangsu Province (No. KYLX15_1166).
*Corresponding author at: Key Laboratory of Advanced Process Control for Light Industry (Ministry of Education), Internet of Thins Engineering, Jiangnan University, Wuxi 214122, PR China.

E-mail address: fding@jiangnan.edu.cn (F. Ding).

http://dx.doi.org/10.1016/j.jfranklin.2016.10.032
0016-0032/

1. Introduction

Parameter estimation aims to seek the true values of systems from observed inaccurate data and plays an important role in system identification [1,2], signal processing [3–5], predictive control [6] and fault diagnosis [7–9]. Many classical methods of estimating system parameters have been reported, such as the prediction error methods [10,11] and the instrumental variable methods [12,13], which are effective for identifying the discrete systems in difference equation forms. However, it is still a challenging task to apply these methods to state space models, because the optimal search of the parameter matrices of state space models often results in nonlinear optimization problems, which generally gives rise to local minimum issues [14].

State space systems have a variety of advantages in system control and optimization [15–17], such as the pole assignment [18] and the observer design [19], but the research progress of state space systems is inferior to that of the difference equation models, whether in the development of the identification theory or in the application of the process modeling [20]. The main reason lies in the states representing that the internal behaviors are unmeasurable. A typical identification algorithm for state space systems is the subspace identification algorithm, which constructs an input–output data compression matrix to estimate the system parameter matrices by using the singular value decomposition and QR factorization, but the computational complexity heavily increases as the dimension of the data compression matrix grows [21,22].

This paper investigates the identification of state space models with colored noise based on the observer canonical form. In this literature, the Kalman state filtering based least squares iterative parameter estimation approach has been developed for observer canonical state space systems using decomposition [23]. Pan et al. studied the image noise smoothing using a modified Kalman filter [24]. The least squares algorithm has been preferred because its principle is simple [25,26]. The problem is that the computational cost of the least squares algorithm rises greatly with the dimension of the covariance matrix, leading to heavy computation especially when the numbers of the calculated parameters are large [27].

Although considerable research has been undertaken on state space systems, the identification of the systems in the presence of colored noise has not been fully studied. By filtering the collected measurement data, this paper derives a filtering based recursive generalized extended least squares (F-RGELS) algorithm, which lowers the effect of colored noise and generates the higher estimation accuracy [28,29]. In contrast to the algorithm in [30], the difference is that all the parameter estimates are refreshed only by employing one filtered model, which simplifies the computational processes but still endures heavy computation, because the dimension of the resulting filtered identification model remains unchanged. To reduce the computational load, the filtered identification model is decomposed into two sub-models with small dimensions and few parameters, and a filtering based two-stage recursive generalized extended least squares (F-TS-RGELS) algorithm is presented. Other identification approaches include the maximum likelihood method [31], the decomposition based method [32], the hierarchical method [33], and the iteration methods [34–37].

The rest of this paper is organized as follows. Section 2 describes the observer canonical state space systems and derives the identification model. Sections 3 and 4 present an F-RGELS algorithm and an F-TS-RGELS algorithm and discuss their convergence. Section 5 simply offers the RGELS algorithm for comparison. Section 6 provides a simulation example. Finally, concluding remarks are given in Section 7.