

Neuro-fuzzy based identification method for Hammerstein output error model with colored noise



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ARTICLE INFO

Article history:

Received 11 July 2016

Revised 27 February 2017

Accepted 11 March 2017

Available online 16 March 2017

Communicated by Steven Hoi

Keywords:

Hammerstein output error model

Separable signal

Neuro-fuzzy

Colored noise

ABSTRACT

In this paper, a neuro-fuzzy based identification procedure for Hammerstein output error model with colored noise is presented. Separable signal is used to realize the decoupling of the identification of dynamic linear part from that of static nonlinear part, and then correlation analysis method is adopted to identify the parameters of the linear part. Next, a filter is embedded to form extended Hammerstein model to calculate the noise correlation function by the information of zeros and poles of the extended model. The correlation functions which consist of the noise correlation function are applied to compensate the bias caused by colored noise. As a result, the parameters of the nonlinear part can be identified through recursive least square method. Examples results illustrate that the proposed approach has high identification accuracy and good robustness to the disturbance of colored noise.

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1. Introduction

Hammerstein model is a classic block-oriented nonlinear model, which consists of the cascade structure of a static nonlinear part followed by a dynamic linear part. It has been pointed that the structure of the model can effectively represent and approximate a large number of industrial processes, for example, distillation column [1, 2], heat exchangers [3], continuous stirred tank reactor [4], pH neutralization process [5] and dryer process [6]. Some identification methods have been used to identify the Hammerstein model. In general, there are mainly two kinds of identification approaches based on the input and output data points for Hammerstein model, namely, synchronous identification approach and separate step identification approach. The basic idea of synchronous identification approach is that the parameters of Hammerstein model are identified by constructing hybrid model of static nonlinear part and dynamic linear part, such as direct identification method [7], over parameterization method [8,9] and subspace method [10–12]. The principle of separate step identification approach is to separate the identification problems of static nonlinear part and dynamic linear part by estimating the immeasurable intermediate variables, such as separable least square method [13], frequency domain method [14,15], iterative method [16–18],

stochastic method [19], special input signal based method [20] and correlation analysis method [21].

Since noise exists in industrial processes, it is very significant to pay more attention to the Hammerstein model with noise. Ding et al. [22] used auxiliary model principal to identify Hammerstein model. The unknown variables can be replaced by the output of auxiliary model, but the first coefficient of the static nonlinear function could be assumed to be one. Auxiliary model recursive least square method based multiple signal identification was applied to Hammerstein model, which solve the limitation that the first coefficient is assumed to be one [23]. In [24], the matrix dimension expansion principle was employed into over parameterization algorithm to compensate errors for Hammerstein model with noise. In recent years, Ding et al. [25] studied recursive least squares method for estimating the parameters of the nonlinear systems based on the model decomposition. In [26], the data filtering-based recursive generalized extended least squares algorithm is derived to improve the estimation accuracy. Jia et al. [21, 27] proposed the correlation analysis method to identify multiple inputs and multiple outputs Hammerstein model, which circumvent the problem of initialization and convergence of the model parameters encountered by the existing iterative algorithms. However, all above mentioned methods only consider the identification of Hammerstein model with white noises. Few papers concerned with the Hammerstein model in the case of colored noise. A Newton iterative method was developed to identify

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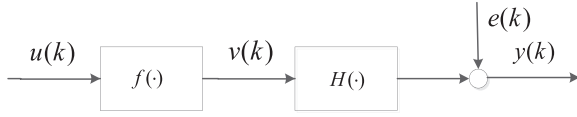


Fig. 1. The structure of Hammerstein output error model.

the parameters of the input nonlinear systems with colored noises using the hierarchical identification principle in [28]. Li et al. [29] studied a parameter identification algorithm of Hammerstein system based on the key term separation technique by using the maximum likelihood principle and stochastic gradient method. In [30], hierarchical least squares iterative identification method was applied to a class of multivariable Hammerstein model in the existence of colored noise. Wang and Ding [31] proposed a recursive generalized extended least square algorithm for nonlinear system with colored noise. But above mentioned methods assumed the colored noise is a linear combination of white noise.

Considering the existing problems of Hammerstein model identification, a neuro-fuzzy based identification procedure for Hammerstein output error model with colored noise is developed in this paper. The identification of the dynamic linear part and the static nonlinear part are carried out independently by using special input signals. The input signal includes separable signal, such as binary signal, Gaussian signal and sine signal, and random multi-step signal with uniform distribution. At first, the correlation analysis method is used to identify the parameters of the linear part. Furthermore, a filter is embedded to form extended Hammerstein model to calculate the noise correlation function by the information of zeros and poles of the extended model, the correlation functions which consist of the noise correlation function are applied to compensate the bias caused by colored noise. Consequently, the parameters of the nonlinear part can be identified by recursive least square.

The rest of this paper is organized as follows. In Section 2, the identification problem of neuro-fuzzy based Hammerstein output error model with colored noise is briefly described. A neuro-fuzzy based identification procedure for Hammerstein output error model with colored noise is presented in detail in Section 3. Section 4 gives simulation examples. Finally, the concluding remarks approached in Section 5.

2. Neuro-fuzzy based Hammerstein output error model with colored noise

Consider the Hammerstein output error model [22] depicted in Fig. 1 that consists of static nonlinear part, $f(\cdot)$ and dynamic linear part, $H(\cdot)$ as given by

$$v(k) = f(u(k)) \quad (1)$$

$$y(k) = \frac{B(z)}{A(z)}v(k) + e(k) \quad (2)$$

where $f(\cdot)$ represents static nonlinear part, $u(k)$ and $y(k)$ denote the Hammerstein model input and output at time k , $v(k)$ is corresponding unmeasurable internal variable, $e(k)$ is the colored noise that is uncorrelated with model input [32], $A(z) = 1 + a_1z^{-1} + a_2z^{-2} + \dots + a_{n_a}z^{-n_a}$ and $B(z) = b_1z^{-1} + b_2z^{-2} + \dots + b_{n_b}z^{-n_b}$ are the parameter vector of the dynamic linear part, a_i and b_j are the parameters of the linear part, n_a and n_b are integers related to the model order.

In paper, the target of the proposed identification approach is to obtain a Hammerstein output error model such that the following

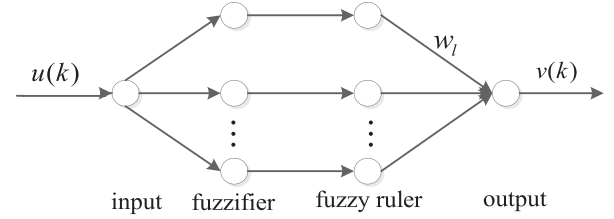


Fig. 2. The structure of neuro-fuzzy model.

cost function is made acceptable small, namely

$$E(\hat{f}(u(k)), \hat{a}_1, \hat{a}_2, \dots, \hat{a}_{n_a}, \hat{b}_1, \hat{b}_2, \dots, \hat{b}_{n_b}) = \frac{1}{2N} \sum_{k=1}^N [y(k) - \hat{y}(k)]^2 \leq \varepsilon \quad (3)$$

s.t.

$$\hat{v}(k) = \hat{f}(u(k))$$

$$\hat{A}(z)\hat{y}(k) = \hat{B}(z)\hat{v}(k) + \hat{A}(z)e(k) \quad (4)$$

where ε is given tolerance, $\hat{f}(\cdot)$ represents the estimated nonlinear function, $\hat{y}(k)$ is the output of Hammerstein model, $\hat{v}(k)$ is estimated internal variable, N is the number of input and output data.

In this paper, the Hammerstein process is identified by a neuro-fuzzy based Hammerstein output error model with colored noise, in which the nonlinearity function $f(\cdot)$ is approximated by neuro-fuzzy model and the dynamic linear part is represented by ARX (Autoregressive Exogenous) model.

As described in Fig. 2, the static nonlinearity of Hammerstein model is approximated by a four layers neuro-fuzzy model which integrates the Takagi-Sugeno fuzzy system and the radial basis function based feed forward network into a connection structure. The first layer is input layer. Nodes in this layer just transmit the input variable to the next layer. The second layer is membership function layer that receives signals from input layer and calculates the membership of input variable, Gaussian membership function is employed in this layer. The third layer is fuzzy ruler layer. The number of the nodes in this layer represents the number of fuzzy rules. The last layer is output layer. All consequence weights w_l are fully connected to the output node in which defuzzification is performed. The output of neuro-fuzzy model is given by

$$\hat{v}(k) = \hat{f}(u(k)) = \sum_{l=1}^L \phi_l(u(k))w_l \quad (5)$$

where

$$\phi_l(u(k)) = \frac{\mu_l(u(k))}{\sum_{l=1}^L \mu_l(u(k))}$$

where $\mu_l(u(k)) = \exp(-\frac{(u(k)-c_l)^2}{\sigma_l^2})$ is the Gaussian membership function, c_l and σ_l is the center and width of membership function, respectively, w_l is corresponding weight of the neuro-fuzzy model, and L is total fuzzy rules. The procedure of identifying neuro-fuzzy model is to estimate the parameters c_l , σ_l and w_l by solving a nonlinear optimization problem.

3. Neuro-fuzzy based identification method for Hammerstein output error model with colored noise

This section presents the identification method of the proposed neuro-fuzzy based Hammerstein output error model with colored noise. The objective of this method is to achieve the identification parameters of the nonlinear part and the linear part. Separable signal is used to identify Hammerstein output error model, resulting in the identification problem of the dynamic linear part separated from that of the static nonlinear part. Our previous work

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