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Parameter identification of wiener systems using the steady-state responses by a novel artificial bee colony algorithm

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Abstract. A novel identification approach is proposed for Wiener systems to avoid error accumulation. The proposed approach identifies the linear and nonlinear part respectively. Firstly, a sequence of step signals with various amplitudes is supplied to the system. The structure of the static nonlinear function is obtained from the input step signals and their corresponding steady-state responses. A novel Artificial Bee Colony (NABC) algorithm is developed to solve the optimization problems and the two experiment studies show that the proposed identification procedure is effective.

1 Introduction

Identification methods of nonlinear system are attracting more and more attentions in recent years [1-3]. It is known that the linear models can only approximate the process around a given operating point, and they cannot be used to deal with the nonlinearity when high-accuracy is demanded. Nonlinear models are better at representing chemical process because it is able to describe the global behaviour of the process over the whole operating range. What's more, nonlinear models can often be used to provide better approximations to process dynamics than linear ones [4]. Wiener system is one of the most frequently used nonlinear model structures [5]. Generally, Wiener system consists of a dynamic linear block followed by a static block which contains all the nonlinearity. Lots of the researchers developed the different approaches of Wiener model identification [6-7].

The paper is organized as follows: Section 2 illustrates the basic ABC algorithm and a novel one while the comparisons are made between them. Section 3 illustrate the identification of the nonlinear part of wiener systems based on the static responses using NABC algorithm. Some case studies are carried out using the proposed method and the advancements are shown in Section 4. The conclusions are made in the last section.

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2 A novel Artificial Bee Colony algorithm

The optimal algorithm classifies the foraging artificial bees into three groups, employed bees, onlooker bees and scout bees. First, the initial population of solutions is generated by the following equation,

$$x_{i,j} = x_{\min,j} + rand(0,1)(x_{\max,j} - x_{\min,j}) \tag{1}$$

where $X_i = \{x_{i,1}, x_{i,2}, ..., x_{i,n}\}$ represent the *i*th food source in the population. And $i = 1, 2, ..., SN$, $j = 1, 2, ..., n$, $x_{\min,j}$ and $x_{\max,j}$ are the lower and upper bounds for the dimension j ,where *SN* is the number of food sources.

The second stage of ABC algorithm, each employed bee generates a new food source V_i by using the solution search Eq. (2) in the neighbourhood of its equation,

$$v_{ij} = x_{i,j} + \phi_{i,j}(x_{i,j} - x_{k,j}) \tag{2}$$

where both k and j are randomly chosen indexes, and k has to be different from i . $\phi_{i,j}$ is randomly chosen in the range [-1,1]. Once the new food source is obtained, the fitness of V_i is calculated. Like other optimal algorithms, a greedy selection mechanism is employed between the old and candidate solutions, where the fitness of V_i will be compared with that of X_i .

After all employed bee finished their searches, an onlooker bee chooses a food source depending on the probability value P_i associated with that food source,

$$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i} \tag{3}$$

where fit_i is the fitness value of solution i .

If a position can't be improved further, then the food source will be abandoned. The value of predetermined number of cycles is an important parameter of ABC algorithm. If the abandoned source is X_i , the scout discovers a new food source to be replaced with X_i by Eq. (1).

To keep a good balance between the global exploration and local exploitation, a novel algorithm NABC is proposed to solve local optimum of ABC and the unknown initial value of New Luus-Jaakola Algorithm (NLJ). The new solution search equation is used for ABC algorithm which is proposed by Gao. [8], devised as follows:

$$v_{ij} = x_{best,j} + \phi_{i,j}(x_{r1,j} - x_{r2,j}) \tag{4}$$

where X_{best} is the best individual vector with the best fitness in the current population and

$j \in \{1, 2, ..., n\}$ is randomly chosen indexes.

The search equation is used because it can increase the exploitation of ABC while the other one described by Eq. (2) is good at exploration but poor at exploitation. Besides, the new search equation makes it possible that the best solutions in the current population are used to improve the convergence performance. Then, the NLJ algorithm is performed to search for a better solution.

3 Identification of nonlinear part using steady-state responses

The structure of Wiener system can be shown in Fig.1. In Fig.1, the unknown dynamic linear part and static nonlinear part can be described by

$$x(k) = G(z)u(k) = u(k)\sum_{i=0}^{\infty}\theta(i)z^{-i}, \quad y(k) = f(x(k);\rho) + e(k) \tag{5}$$

where $u(k)$, $x(k)$ and $y(k)$ represent for the input, internal signal and the output at time $k = 0,1,...,N$. $G(z)$ is the transfer function of the linear part and $f(\cdot)$ is the nonlinear function. When the linear part of Wiener system is stable, the system must be standardized to guarantee identifiability. The structure of the nonlinear block of Wiener system and the internal signal are unknown. It is assumed that $\|\theta\|^2 = \sum_{i=0}^{\infty}\theta(i)^2 = 1$, where $\theta = (\theta(0), \theta(1), ...)^T$ is an infinitely dimensional vector. Obviously, the signals of the system are bounded due to the stability property and bounded input. Thus, assuming that

$$\theta_n = (\theta(0), \theta(1), ..., \theta(n-1))^T \tag{6}$$

where n is a give positive integer. So $\sum_{i=n}^{\infty}\theta(i)^2 \to 0$ as $n \to \infty$ due to the stability assumption $\sum_{i=0}^{\infty}\theta(i)^2 = 1$. It is equivalent to $\|\theta_n\|^2 \to 1$ as $n \to \infty$. As a result, for the dynamic linear block of Wiener system, only the first n parameters need to be identified. Thus, the linear block can be obtained by

$$x(k) = \underbrace{(u(k), u(k-1), ..., u(k-n+1))}_{\phi^T(k)}\theta_n \quad k = 1, 2, ..., N. \tag{7}$$

The parameter vector θ_n of the linear block is identified by the data set $\{\phi(k), y(k)\}$, $k = 1, 2, ..., N$. Further, the nonlinear block $f(\cdot)$ is identified. The linear and nonlinear part of Wiener systems are identified to avoid error accumulation, respectively. The issue of the linear block will be solved by the limited information of the nonlinearity. And the identification problem of nonlinear block will be solved by using the steady-state responses by step signals. Here an internal constant $\hat{\Phi}$ must be used to ensure the partnership of the output signals and the input signals, which is determined by the average of the steady-state response. The modified Wiener structure is shown in Fig.2. The identification of the static nonlinear part and the dynamic linear part of Wiener system will be detailed in the following sections.

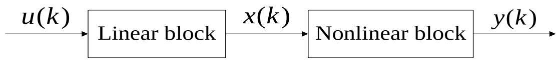

Fig.1. Wiener system.

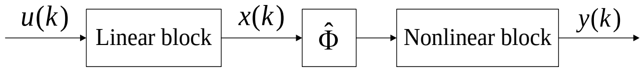

Fig.2. A modified structure of Wiener system.

Supposing a step signal with amplitude h is supplied to the Wiener system. From the assumption that the linear block is stable, the steady-state response of the dynamic linear sub-system to this step signal is

$$x_r = \lim_{z \to 1} G(z)h = h \lim_{z \to 1} \sum_{i=0}^{\infty} \theta(i) z^{-i} \tag{8}$$

From Eq. (5) and Eq. (6), the following equation can be derived as

$$x_r = h \lim_{z \to 1} \sum_{i=0}^{n} \theta(i) z^{-i} = h \sum_{i=0}^{n-1} \theta(i) = hK \tag{9}$$

where $K = \sum_{i=0}^{n-1} \theta(i)$ is the gain of the dynamic linear subsystem. From Eq. (9), it is obvious that the input of the static nonlinear block is a constant, which is proportional to the amplitude h when the system is in steady-state. So an input and output pair (x_r, y_r) can be obtained where y_r represents the output signal of the static nonlinear part. To identify the static nonlinear function described in Eq. (5), N pairs of steady-state responses are needed. Let $h_1, h_2, ..., h_n$ are the amplitude of N step signals supplied to the system. Thus, N pairs of state responses can be obtained. However, the construction of the nonlinear function is unknown, but the picture of $f(\cdot)$ can be graphed. Then the structure information from the graphical picture can be given [9]. The next step is to estimate the unknown parameters ρ and K from the input-output data set. The following optimization problem can be performed to achieve the goal

$$(\hat{\rho}, \hat{K}) = \arg\min \frac{1}{L} \sum_{i=1}^{L} [y_{r_i}(k) - f(h_i \hat{K}; \hat{\rho})]^2 \tag{10}$$

The NABC algorithm proposed by this paper is performed to solve the optimization problem.

4 Simulation study

In this section, a numerical simulation will be studied to illustrate the effectiveness of the proposed method.

A numerical simulation example is provided for the linear part be a fourth order sub-system. And the nonlinear part of the system is a typical nonlinearity. The system is presented by

$$G(z)=\frac{0.75z^{2}+0.60}{z^{4}+0.1z^{3}+0.25z^{2}+0.40}.$$

$$y=f(x)=0.15x+1.3(e^{0.6x}-1)$$

Fig. 3 shows the impulse response of the linear block where the black dots represent the values at sampling time and Fig. 4 shows the characteristic of the nonlinear part.

In Fig. 4, the structure of the nonlinearity satisfies all the three conditions which are discussed in the previous sections. So, the linear part of the system is identified by the proposed methods based on the limited information of the static nonlinear block. The input $u(k)$ is independence identically distributed uniformly in [-1, 1] and the Gaussian noise is added to the output.

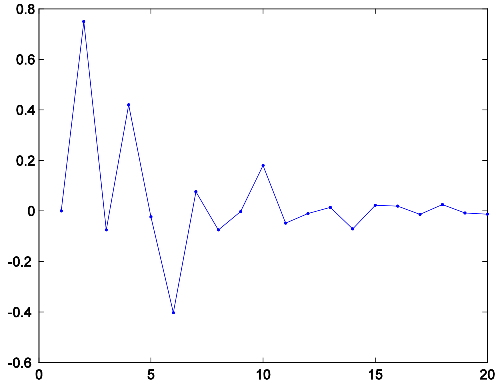

Fig. 3. Impulse response of the linear part.

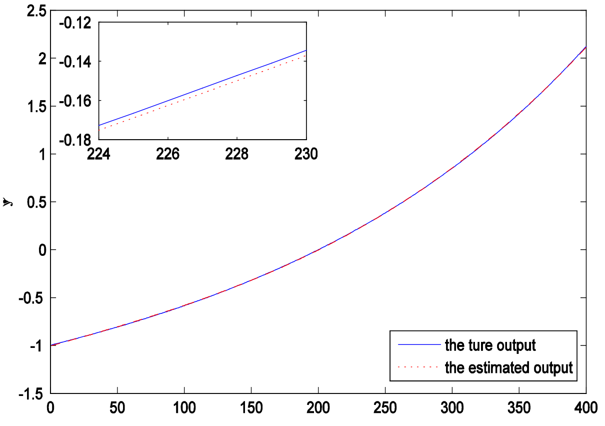

Fig. 4. Steady-state response of Wiener system.

5 Conclusions

An identification method is proposed for Wiener system which identify the static nonlinearity and the dynamic linear block respectively. A steady-state response is used for estimating the nonlinearity. Simulations illustrate that the structure presented in the paper can obtain a good approximation of Wiener system.

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