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Least squares based iterative identification for multivariable integrating and unstable processes in closed loop

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ABSTRACT

Inspired by the fact that those multivariable integrating and unstable processes are usually operated in a closed loop manner for safety and economic reasons, an improved iterative least squares identification method is proposed, which is detailed for a second-order plus dead-time (SOPDT) model. The iterative computation process is able to availably weaken the effect of errors caused by first-order *Taylor* series approximation for time delay items. And the least squares based iterative identification algorithm has fast convergence rates and effectively improves the accuracy of the process parameter estimates in noisy environments. Also, the proposed algorithm can be further extended to multivariable closed loop systems via the equivalent inputs and outputs. Simulation examples verify the validation of the proposed method for multivariable integrating and unstable processes in closed loop.

1. Introduction

In many industrial systems, multivariable processes are often seen where each control loop will be affected inevitably by other loops. For safety and economic reasons, those multivariable integrating and unstable processes are usually not allowed to be operated in an open loop manner, closed loop identification methods have therefore been developed [1,2]. In a word, it is very useful to identify a full model of such a process for control purpose. For a wide range of multivariable processes [3], some of them that contain integrating factors or unstable poles in their transfer function matrices should also be taken into account.

The real issue in closed loop identification exists in the correlation between the disturbances and the manipulated variables through the feedback. This brings additional challenges for system identification in the closed loop conditions [4,5]. In order to solve the problem, Ljung [6] has extended the prediction error method to develop the identification of multivariable systems. And three approaches are introduced for closed loop identification, i.e., *the direct approach, the indirect approach* and *the joint input–output approach*. They all belong to a framework of the basic prediction error method.

Since the continuous time delay systems that can be parameterized into a class of linear regression forms are more close to the real systems in an intuitive way, the linear differential equation of a continuous time delay process is considered in this paper. According to the linear regression form, the least squares identification algorithms are of substantial importance in parameter estimation based on measured input–output data and have fast convergence rates [7–17]. Meanwhile, the actual process models often include time delay parts [18,19], while many identification methods do not consider them, or

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assume that they are known. One reason is that the existence of dead time hardly gives the rigorous expressions of time-shifted input signals. Another reason is that first-order *Taylor* series approximation for time delay items may results an inconsistent parameter estimation although this approximation is a general method to reduce the computational burden. In this paper, to overcome the problem involved in identifying system time delays, a least squares based iterative identification algorithm [20–25] is developed to availably reduce the effect of errors caused by first-order *Taylor* series approximation for time delay items.

As low-order process models are mostly used for chemical control system design and on-line tuning [26,27], the widely used low-order process models of second-order plus dead-time (SOPDT) are adopted for the purpose of identification. Despite of the less-persistent excitation property of the input functions [28,29], the proposed identification method has been successfully developed to identify the parameters of SOPDT models directly from the system inputs and outputs [30]. Meanwhile, the identification of a multivariable closed loop process is converted into the identification of multiple independent single open loop systems via the equivalent inputs and outputs, reducing the complexity of multivariable identification.

In this paper, Section 2 shows the widely used low-order process models of second-order plus dead-time (SOPDT). An iterative least squares algorithm for a single-input single-output (SISO) system is given in Section 3. Further, Section 4 solves the identification problem of a multivariable closed loop system by decoupling the process into multiple independent single open loop processes. Two illustrative examples are presented for the results in Section 5. Finally, conclusions are drawn in Section 6.

2. Identification model

Consider a second-order plus dead-time (SOPDT) model as following:

$$G(s) = \frac{Y(s)}{U(s)} = \frac{K}{a_2 s^2 + a_1 s + 1} e^{-\tau s}. \tag{1}$$

However, this type of model is not suitable for no self-regulating process. Further, this section also studies the following model of (2a) to extend the scope of applications.

$$G(s) = \frac{Y(s)}{U(s)} = \frac{\widetilde{K}}{s^2 + \widetilde{a}_1 s + \widetilde{a}_0} e^{-\tau s}. \tag{2a}$$

When $\widetilde{a}_0 \neq 0$, (2a) is equivalent to (1), i.e., $\widetilde{K} = K/a_2$, $\widetilde{a}_1 = a_1/a_2$, $\widetilde{a}_0 = 1/a_2$. When $\widetilde{a}_0 = 0$, the model can describe a kind of no self-regulating processes with a pole $s = 0$, i.e., the integrator and dead time processes. By removing $\widetilde{\bullet}$ in (2a), it is expressed as below.

$$G(s) = \frac{Y(s)}{U(s)} = \frac{K}{s^2 + a_1 s + a_0} e^{-\tau s}. \tag{2b}$$

It is worth noting that any of process parameters $\{a_1, a_0\}$ may be negative which corresponds to a non-minimum-phase process. For the SOPDT models described in (2b) including the integrating and unstable processes, an iterative least squares algorithm is developed to identifying the parameters $\{K, \tau, a_1, a_0\}$ of models in this paper.

3. Iterative least squares algorithm for SISO system

In view of the single-input single-output (SISO) system, we need to consider the time delay τ in (2b) first. The delay τ is decomposed into the sum of the initial value τ_0 and compensation value τ_p. Thus, it yields

$$\tau = \tau_0 + \tau_p, \tag{3}$$

where τ_0 is determined previously. These two parameters $\{\tau_0, \tau_p\}$ are unknown and need to be estimated in the identification algorithm (Firstly see Remark 1 for more details on how to obtain the initial value τ_0).

Then, Eq. (2b) can be equivalently written as

$$\frac{Y(s)}{U(s)} = \frac{K e^{-\tau_p s}}{(s^2 + a_1 s + a_0) e^{\tau_0 s}}. \tag{4}$$

First-order *Taylor* series approximation for compensation value τ_p of time delay gives

$$e^{-\tau_p s} \doteq 1 - \tau_p s. \tag{5}$$

Substituting (5) into (4) yields

$$\frac{Y(s)}{U(s)} = \frac{K(1 - \tau_p s)}{(s^2 + a_1 s + a_0) e^{\tau_0 s}}. \tag{6}$$

Using an inverse Laplace transformation, the linear differential equation of the process model is obtained as following.