Applied Mathematical Modelling 35 (2011) 594–611

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Indirect identification of continuous-time delay systems from step responses

Yan Yi Du [a], Jason S.H. Tsai [a,*], Harshal Patil [b], Leang S. Shieh [b], Yuhua Chen [b]

[a] Control System Laboratory, Department of Electrical Engineering, National Cheng Kung University, Tainan 701, Taiwan, ROC
[b] Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77204-4005, USA

ARTICLE INFO

Article history:
Received 8 September 2009
Received in revised form 7 June 2010
Accepted 5 July 2010
Available online 15 July 2010

Keywords:
Indirect identification
Modified *Z*-transform
Step response
Least-squares algorithm
Time delay system

ABSTRACT

In this paper, an indirect identification scheme is proposed for identifying the parameters of the continuous-time first-order plus time delay (FOPTD) model and the second-order plus time delay (SOPTD) model from step responses. Unlike the existing direct identification scheme, which identifies the parameters of the continuous-time FOPTD and SOPTD models directly from the continuous-time step response data, the proposed indirect scheme is to pre-identify discrete-time FOPTD and SOPTD models from the discretized continuous-time step response input–output data, then convert the obtained discrete-time models to the desirable continuous-time models. The proposed method is then extended to identify the afore-mentioned models from the step responses of the systems contaminated with input noise and constant output disturbance. The proposed simple alternative method exhibits good estimation performances in both the time domain and the frequency domain. Illustrative examples are presented to demonstrate the effectiveness of the proposed scheme.

1. Introduction

Most real industrial processes are often formulated in continuous-time settings and can be represented by the continuous-time first-order plus time delay (FOPTD) and second-order plus time delay (SOPTD) models [1,2]. When the parameters of the continuous-time processes are unknown, various sophisticated indirect identification methods have been developed and can be found in the literature [3–5], and a few direct identification methods can be found in [6,7]. In addition, the sophisticated methods for estimations of the dead times for the unknown systems can be found in [8,9]. In general, the afore-mentioned identification methods require that the excitation inputs for the unknown systems must be persistent [10]. Nevertheless, in the processes control, the unit-step function, which is not a persistent excitation signal, is commonly used as a reference input to verify the performances of the systems and to specify the control specifications [1,11] in the time domain, such as the percentage overshoot, rising time, settling time, etc. Despite the less-persistent excitation property of the step input function, several direct identification methods [12–20] have been successfully developed to identify the parameters of the continuous-time FOPTD and SOPTD models directly from the continuous-time step response data.

In this paper, a simple indirect identification scheme is proposed for identifying the FOPTD and SOPTD models from step responses. The proposed indirect scheme is to pre-identify a discrete-time FOPTD and SOPTD models from the discretized continuous-time step-input and its output response, and then convert the obtained discrete-time models to the desirable continuous-time models. The proposed method is then extended to identify the afore-mentioned models from the step responses of the systems contaminated with input noise and constant output disturbance. The proposed alternative method

* Corresponding author. Tel.: +886 6 275 7575x62360; fax: +886 6 2345482.
E-mail address: shtsai@mail.ncku.edu.tw (J.S.H. Tsai).

0307-904X/$ - see front matter
doi:10.1016/j.apm.2010.07.004

exhibits good estimation performance in both the time domain and the frequency domain. Illustrative examples are presented to demonstrate the effectiveness of the proposed scheme.

The paper is organized as follows: indirect identification methods to estimate FOPTD and SOPTD models are presented in Section 2. To overcome the interference of output constant offset, two elimination methods are developed in Section 3. The procedure of the proposed algorithms is summarized in Section 4. Simulation examples are presented in Section 5, and conclusions are given in Section 6.

2. Indirect method to identify FOPTD and SOPTD models

2.1. Problem formulation

Consider the output response function $Y(s)$ of a continuous-time delay system $G(s)$ with zero initial condition described by

$$Y(s) = G(s)R(s) = G_p(s)e^{-Ls}R(s), \tag{1a}$$

where $R(s) = 1/s$ denotes the input step signal, L is a dead time such that the output $y(t)$ satisfies $y(t) \cong 0$ for $t \leqslant L$, and $G_p(s)$ is a delay-free plant with unknown parameters to be identified. The same output function in (1a) can be represented as

$$Y(s) = G_p(s)e^{-Ls}H_o(s)R(s), \tag{1b}$$

where $H_o(s) = (1 - e^{-sT})/s$ is a function of a sampler and zero-order hold (ZOH) with the sampling period T, and the dead time L is defined as $L = (d - 1)T + \gamma T$ for $d \in N$ and $0 \leqslant \gamma \leqslant 1$.

Then, the Z-transform of the discretized output function $Y(s)$ in (1a) and (1b) is written as

$$Y(z) = Z\{G_p(s)e^{-Ls}R(s)\} = Z\{G_p(s)e^{-Ls}H_o(s)R(s)\} = Z\{G_p(s)e^{-Ls}H_o(s)\}Z\{R(s)\} = Z\{G_p(s)e^{-Ls}H_o(s)\}R(z), \tag{2a}$$

where $Z[\cdot]$ represents as Z-transform operator. The corresponding pulse transfer function becomes

$$\frac{Y(z)}{R(z)} = Z\{G_p(s)e^{-Ls}H_o(s)\} = z^{-(d-1)}(1 - z^{-1})Z\left\{\frac{G_p(s)e^{-\gamma Ts}}{s}\right\} = z^{-d}(z - 1)Z\left\{\frac{G_p(s)e^{-\gamma Ts}}{s}\right\}. \tag{2b}$$

Fig. 1 represents the block diagram of (1) and (2).

The aim of the paper focuses on identifying the unknown parameters in an approximate time delay model $\widehat{G}(s)$ with an unknown integer d and a fractional value γ of the dead time L by utilizing the input–output data obtained from the real systemG(s). The corresponding block diagram of the identification structure is depicted in Fig. 2.

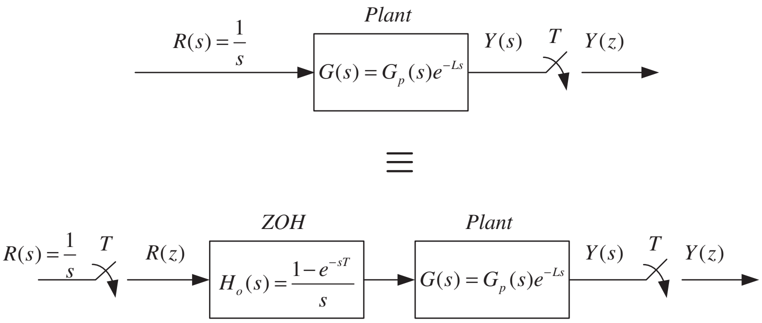

Fig. 1. Sampled-data system with step response.

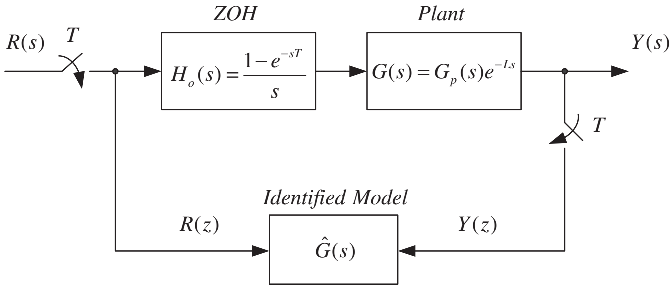

Fig. 2. System identification for a sampled-data system with time delay.