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Simple graphical method for noisy pulse and step responses

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ABSTRACT

A pulse test is one of the simplest identification tests. Here a simple graphical method that uses the integral of pulse response and identifies a first order plus time delay (FOPTD) model is proposed. It can be effectively applied to noisy pulse responses because the integral of the pulse response is used. It can also be applied to noisy step responses, improving the previously developed area method.

1. Introduction

Various identification methods ranging from simple graphical methods to elaborate numerical methods have been available for linear systems. Each method has its own advantages. For PID (proportional-integral-derivative) controller tuning, a simple empirical model such as FOPTD and a graphical identification method can be used. One of the simplest identification methods for this is a graphical method using the step response (Seborg et al., 2004). Step response identification permits visualizing various aspects of process dynamics such as type and speed of the process response. For some processes, especially when a long sustained upset is not desirable, a pulse test is useful because the pulse test will not disturb the process as much as the step test. However, different from the step response, a simple graphical method to analyze the pulse response is not currently available. Here a graphical method using the integral of the pulse response is proposed, which is very similar to the graphical method for the step response. Because the integral of the response is used, it can be used for noisy environments.

The area method (Åstrom and Hägglund, 1995) has been used for simple identification of the FOPTD model from noisy step responses. However, it is very sensitive to errors in the identified steady state gain when the final time of the step response for identification is large. To reduce such sensitivity, the above method based on the integral of pulse response is extended to identify the FOPTD model from noisy step responses. For this, the difference of the step response, which corresponds to a pulse response, is used.

Integrals of pulse and step responses are easy to obtain in data acquisition systems and simple graphical methods provide insights about process dynamics. The proposed methods can also be used to obtain initial estimates before applying more elaborate methods to identify FOPTD models from pulse and step responses.

2. Integral of pulse responses (IPR)

Consider a FOPTD process

$$G(s)=\frac{k\exp(-\theta s)}{\tau s+1} \tag{1}$$

The response $y_S(t)$ for the step input of size M is (Seborg et al., 2004)

$$y_S(t)=\begin{cases}0, & 0\le t<\theta\\ kM(1-\exp(-(t-\theta)/\tau)), & \theta\le t\end{cases} \tag{2}$$

Let the new steady state output be y_{inf} and $a_1 y_{inf}$ and $a_2 y_{inf}$ be the outputs at times t_1 and t_2, respectively. From Eq. (2), we have $y_{inf}=kM$, $a_1=1-\exp(-(t_1-\theta)/\tau)$ and $a_2=1-\exp(-(t_2-\theta)/\tau)$, and consequently

$$k=y_{inf}/M$$

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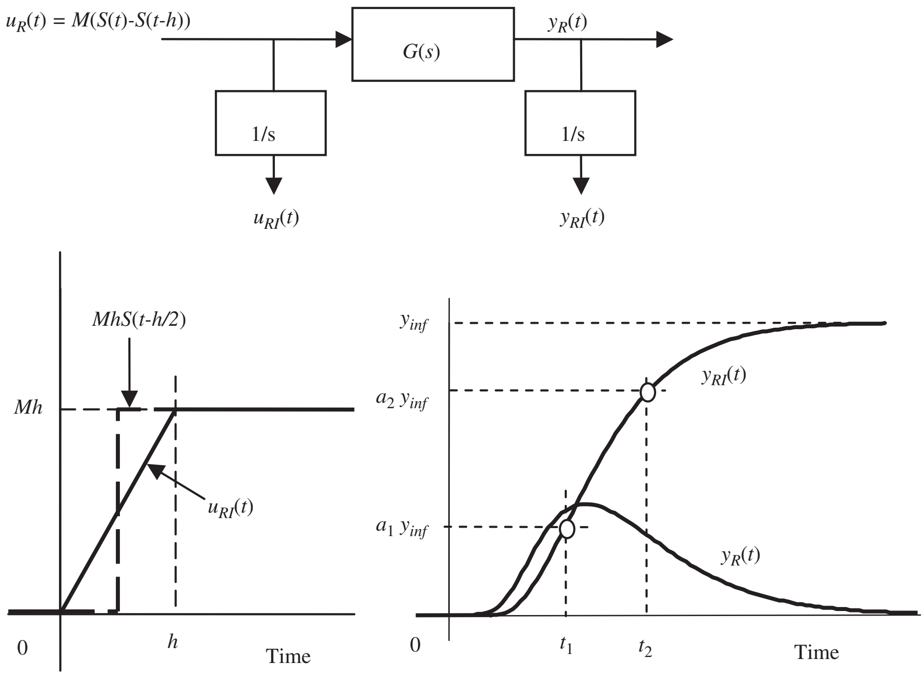

Fig. 1. Integrals of rectangular pulse input and output responses.

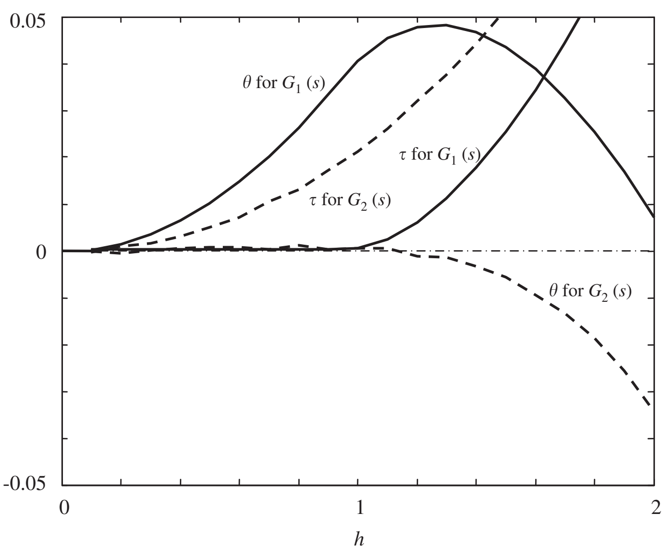

Fig. 2. Identification errors ($\tau_{estimate}-1$) and ($\theta_{estimate}-1$) versus the pulse duration h for processes of $G_1(s)=\exp(-s)/(s+1)$ and $G_2(s)=\exp(-0.580s)/(0.687s+1)^2$.

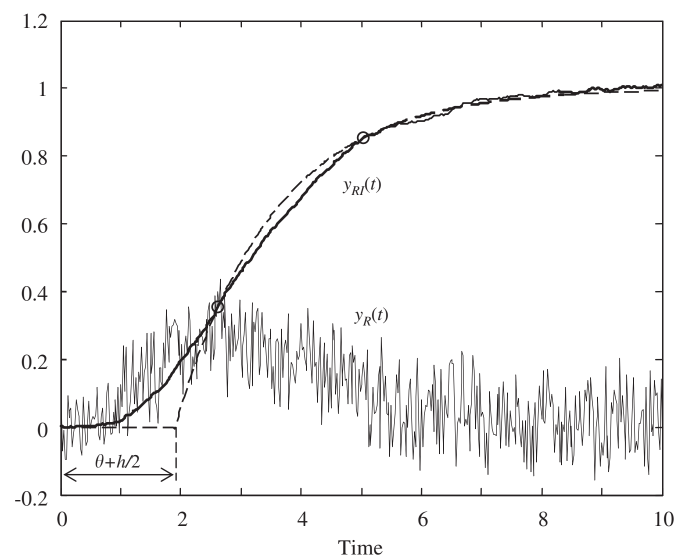

Fig. 3. Fitting results for the rectangular pulse input under noisy environment ($G(s)=1/(s+1)^3$).

$$\tau=\ln\left(\frac{1-a_2}{1-a_1}\right)(t_2-t_1)$$

$$\theta=\frac{\ln(1-a_2)}{\ln(1-a_2)-\ln(1-a_1)}t_1+\frac{-\ln(1-a_1)}{\ln(1-a_2)-\ln(1-a_1)}t_2 \tag{3}$$

Sundaresan and Krishnasvamy (1978) recommended for best overall results to use a_1=0.353 and a_2=0.853. The resulting model parameters are

$$\tau=0.6748(t_2-t_1)$$

$$\theta=1.2938t_1-0.2938t_2 \tag{4}$$

Other values for a_1 and a_2 can also be used, depending on user experience. This method is called as the two-point method. This method is difficult to apply for noisy step responses.

Classical methods to analyze the pulse response are the moment method and the frequency response method (Johnson et al., 1971). Both methods use several integrations of the pulse response. Fitting of the pulse response requires nonlinear optimization (Ham and Kim, 1998). Recently, Hwang and Lai (2004) obtained linear relationships between the process output and its integrals for low-order models with time delay, and proposed a linear least squares method to identify those model parameters. However, it shares advantages and disadvantages of other numerical methods. Here a simple graphical method which