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Sliding mode predictive control for long delay time systems

Feipeng Da

Southeast University, Automation Research Institute, SiPaiLou No. 2, 210096 Nanjing, China

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Abstract

Delay time, which may degrade the control performance, is frequently encountered in various systems. In this Letter, a sliding mode controller (SMC) based on fuzzy prediction algorithm is presented to control the long delay systems. According to the characteristics of the long delay systems, we simulate the manual operating process and predict the delayed error and its increment based on the information of the input and output variables of the system, and then feedback these prediction values to the sliding mode controller. Simulation examples demonstrate the advantages of the proposed control scheme.

Keywords: Sliding mode control; Fuzzy prediction; Long delay time

1. Introduction

Many dynamical systems, such as paper-making processes, glass melting furnace, chemical processes, thermal processes, communication channels, etc., contain time delay or dead time. Due to the delay, the output of the system could not follow the control input in time, so it is difficult to control such system effectively. In some cases delay time can make the system unstable. The survey paper [1] shows that many researches have been done on the delay processes.

Sliding mode control is one of the powerful control methods for nonlinear systems due to its good control performances and robustness [2]. A detailed description is given in [1] about the applications of the sliding mode control in the delay system. Some other new researches are included in [3–5]. In [3], a neural network based sliding mode controller is proposed for a class of state-delayed systems with mismatched parameter uncertainties, unknown nonlinearities and external disturbances. The major advantage is the relaxation of the requirement that the unknown nonlinearities are to be bounded. For a class of point-delayed systems, sliding mode control is used in [4] where a linear transformation is applied to convert the delayed system to delay-free system. In [5], based on integral sliding mode compensator of disturbance, a robust algorithm for the optimal regulator is presented for linear systems with multiple time delays in control input.

E-mail address: dafp@seu.edu.cn (F. Da).

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In the general SMC design, the current system state variables are needed. But in the delay system, we cannot get the system state variables in time. In this case, if we still control delay system based on current state variables, the system will be unstable and we cannot get the desired control performance. So in the Letter, a new controller, including the sliding mode and the fuzzy prediction, is presented for the long delay system. According to the characteristics of the long delay, we simulate the manual operating process and predict the delayed error and its derivatives based on the information of the input and output variables, and then feedback these prediction values to the sliding mode controller. Simulation examples show that the proposed method has more robustness even when the delay time is changing in the control process.

Remark 1. In the Letter, the long delay time system is defined for a second order system with the form of $\ddot{y}(t) + a\dot{y}(t) + by(t) = bu(t - L)$, where L, a, b are positive constants, L the delay time. We call the system as the long delay system if $L\sqrt{4b - a^2} \geqslant 10\pi$.

2. Controller design

In the practical manual control process, for the long delay system, an experienced operator is always observing the values and their changing directions of the input and the output, judging the values and their changing speed and directions of the errors in the same time, and predicting the next step's value and the changing direction of the output error, then based on all these input and output increment information, making the decision on how to tune the controller to let the output of the controlled process to track the desired output after the long delay time L. This is a successful method in the real use. So in the Letter we try to use fuzzy prediction to mimic this manual operation and then design a sliding mode controller to control such kind of long delay system.

The block diagram of the whole system is shown in Fig. 1, where SMC denotes the sliding mode controller, the input of the plant is $u(t)$, the output $y(t)$, and the desired output $y_r(t)$. In the prediction part, there have two inputs, one is $\delta u(t)$ denoting the control input increment after the delay time L, another is $\Delta y(t)$ which reflects the output increment after one step. The output of the prediction part are $\hat{e}(t+L)$ and $\Delta\hat{e}(t+L)$, which represent the prediction values of the error and its increment after the delay time L, respectively. Then in the system, the obtained $\hat{e}(t+L)$ and $\Delta\hat{e}(t+L)$ are fed to the SMC as inputs.

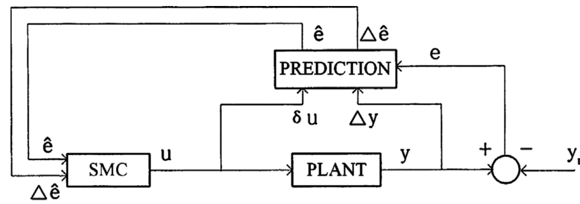

Fig. 1. Block diagram of the prediction control system based on SMC.

Remark 2. In the Letter, some symbols are defined. Δ represents the increment value after one step, δ represents the increment value after a delay time L, for example, $\Delta u(t) = u(t) - u(t-1)$, $\Delta y(t+L) = y(t+L) - y(t+L-1)$, $\delta u(t) = u(t) - u(t-L)$, $\delta y(t+L) = y(t+L) - y(t)$.

2.1. Fuzzy prediction

For the system with pure delay L, its control input will be effective only after the delay time L. So it is necessary to give a correct estimation of the system states after the delay L. This estimation process include two steps: firstly, to estimate the output increment $\delta y(t+L)$ after the delay time L based on the input increment $\delta u(t)$ and the output increment $\Delta y(t)$. This estimation process can be written as $(\delta u(t), \Delta y(t)) \to \delta\hat{y}(t+L)$. Secondly, in the error prediction part, deriving $\hat{e}(t+L)$ and $\Delta\hat{e}(t+L)$ from the obtained $\delta\hat{y}(t+L)$.

Denoting the controller output $u(t) = \delta u(t) + u(t-L)$. Output increment $\Delta y(t)$ represents the influence of the input series $\{u(\xi)|0 < \xi \leqslant t\}$. Fig. 2 gives the behaviors of $\Delta y(t)$ and $\delta\hat{y}(t+L)$ when $\delta u(t)$ is positive big. If we use fuzzy rules to describe [6], we can get the following fuzzy rules:

rule 1: if $\delta u(t)$ is PB and $\Delta y(t)$ is PB,
then $\delta\hat{y}(t+L)$ is PB,

rule 2: if $\delta u(t)$ is PB and $\Delta y(t)$ is PM,
then $\delta\hat{y}(t+L)$ is PM,