Adaptive IMC for variable parameter systems with large dead-times

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Abstract

Dead-time variation can cause object mismatches in traditional internal model control (IMC) systems and may result in a significant overshoot. The adjustment time may increase due to this variation and sometimes even causes oscillation instability. An adaptive IMC method is proposed in this paper to solve the problem of variable parameters in the control process. The adaptive law is designed to optimize local parameters relative to the output error of both the plant and model, ensuring that the model approximates the real plant. The control structure adopts IMC and simulation results show that this type of control structure exhibits some promising characteristics, such as high accuracy, robustness and disturbance rejection. This model is therefore suitable for systems with large dead-time varying parameters.

Keywords: Large dead-time, Internal model control (IMC), Adaptive, Variable parameter

1 Introduction

The internal model control (IMC) algorithm is widely used in dead-time process industries because of its simplicity and practical success. A well-designed IMC controller has been proved to be sufficient for a large number of dead-time control loops. However, when dead-time variation is present, although advanced control techniques can provide significant improvements, in general the output of a conventional IMC cannot adapt quickly enough to reflect the current system conditions and results in a significant overshoot. Simultaneously, the adjustment time increases and sometimes even causes oscillation instability. Where the dead-time is varying and the object parameters are also changing, the problem becomes even more complicated, and a quality control system cannot be achieved using conventional Smith predictor, optimal control or other similar algorithms [1-3]. With ordinary dead-time systems, overcoming the impact of dead-time is a key issue in the design process of the controller. For a dead-time system where the object parameters are varying, we not only need to overcome the effects due to time delays, but also need to identify changes to the object parameters. This paper presents a design for an adaptive identification IMC to track changes in object parameters and overcome the impact of dead-time. Additionally, this design benefits from IMC's characteristics such as simple structure, easy and intuitive design, less online parameter adjustment, and a simple and clear adjustment method that does not exhibit any static error when in steady-state. It also efficiently improves the anti-jamming performance and large dead-time system control effect [4-7].

2 Adaptive IMC Design

IMC was derived by Brosilow and Tong in 1978 on the basis of Smith Predictor compensation control. The model can be represented as a basic control structure using a Single Input/Single Output (SISO) block diagram. Using the general delay system IMC design presented in [4], we have selected a first-order system with a time delay controlled object. The control structure is shown in figure1.

The object model is:

$$G_M(s) = [K_m/(T_m s+1)]e^{-\tau_m s}. \tag{1}$$

The controller is:

$$G_c(s) = (T_m s+1)/K_m. \tag{2}$$

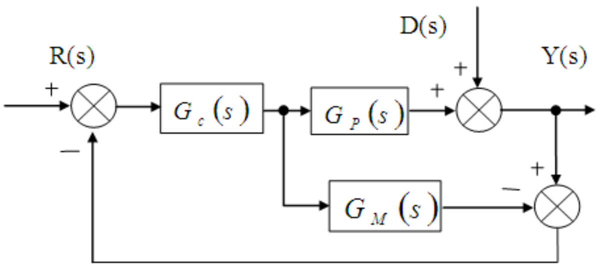

FIGURE 1 IMC structure

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The model can be considered to be a PD controller, since noise is inevitable in real-world industrial processes; therefore we have added a first-order filter after the controller to improve the robustness of the system. The larger the time constant of the filter, the better the system robustness, however the transition process becomes longer as the time constant increases [1]. The control system has good quality control once the model matches the object, but when there is a mismatch, the quality of the system will deteriorate, or even become unstable. An adaptive mechanism is therefore important to identify object parameters, thus improving the robustness of the system. We will now examine the adaptive identification object parameters in more detail.

Suppose the transfer function of the actual object is:

$$G_p(s) = K\frac{N(s)}{D(s)}e^{-\tau_p s}. \tag{3}$$

Due to the complexity of the industrial process, the parameters within either of the two transfer functions are likely to change.

The parameters can be divided into two categories: (a) rational fraction polynomial parameters, such as the Molecular denominator polynomial coefficients of $K\frac{N(s)}{D(s)}$, and (b) time delay parameters. Further detail on identification of the rational fraction polynomial parameters is given in [3], in this paper, these parameters are fixed as constants. This work focuses on delay parameter identification with local parameter optimization theory to design the adaptive law. The adaptive identification delay parameter diagram is shown in figure 2.

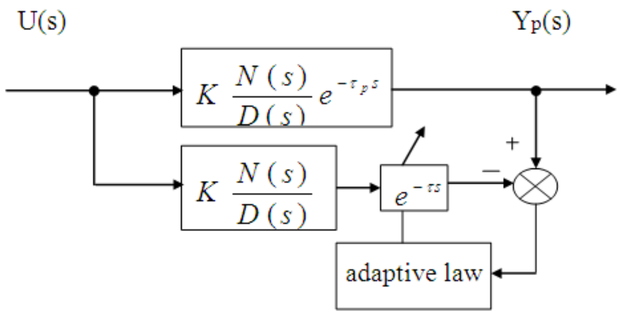

FIGURE 2 Adaptive identification agency

Assuming the prediction model is:

$$G_m(s) = K\frac{N(s)}{D(s)}e^{-\tau s}. \tag{4}$$

The selected performance indicators are:

$$J = \frac{1}{2}\int_{t_0}^{t} e^2(t)dt, \tag{5}$$

where

$$e(t) = y_p(t) - y_m(t) \tag{6}$$

and

$$\frac{Y_p(s)}{U(s)} = K\frac{N(s)}{D(s)}e^{-\tau_p s}, \tag{7}$$

$$\frac{Y_m(s)}{U(s)} = K\frac{N(s)}{D(s)}e^{-\tau s}. \tag{8}$$

Using Massachusetts Institute of Technology (MIT) adaptive law, we obtain:

$$gradJ = \frac{\partial J}{\partial \tau} = \int_{t_0}^{t} e(t)\frac{\partial e(t)}{\partial \tau}dt. \tag{9}$$

The scanning step is λ, and τ is designed based on the performance indicators in the negative direction gradient.

$$\tau = -\lambda.gradJ = -\lambda\int_{t_0}^{t} e(t)\frac{\partial e(t)}{\partial \tau}dt, \tag{10}$$

$$\dot{\tau} = -\lambda e(t)\frac{\partial e(t)}{\partial \tau}. \tag{11}$$

Using (9) and y_p, which is independent of τ, we obtain:

$$\dot{\tau} = \lambda e(t)\frac{\partial y_m(t)}{\partial \tau}. \tag{12}$$

From (10) and (11) we obtain:

$$\frac{Y_p(s)}{Y_m(s)} = e^{(\tau-\tau_p)S} \therefore Y_m(s) = Y_p(s)e^{-(\tau-\tau_p)S}, \tag{13}$$

$$\therefore \frac{\partial y_m(t)}{\partial \tau} = L^{-1}\left[\frac{\partial Y_m(s)}{\partial \tau}\right]. \tag{14}$$

From (12), (13) and (14) we obtain:

$$\dot{\tau} = -\lambda e(t)L^{-1}\left[sY_p(s) * e^{-(\tau-\tau_p)s}\right]$$

$$\therefore \dot{\tau} = -\lambda e(t)L^{-1}\left[SY_m(s)\right] \therefore \dot{\tau} = -\lambda e(t)\frac{dy_m(t)}{dt}$$

$$\therefore \tau = -\lambda\int_{t_0}^{t} e(t)\frac{dy_m(t)}{dt}dt + \tau_0. \tag{15}$$

τ_0 is the initial value of the reference model, and generally taken as the maximum probable value of the object time delay. Equation (15) is the resulting adaptive law.

3 Simulation

The simulation model is shown in figure 3, without loss of generality, the controlled object is [8]:

$$G_p(s) = \frac{K}{Ts+1} e^{-\tau s}, \tag{16}$$

where T and K are known and assumed constant throughout the process and τ is the pure delay time which is changing throughout the process. Let K=3, T=10 and use a maximum probable value of τ of 50, i.e. τ_0 =50.

From part 2 we obtain the structure of IMC as:

$$G_c(s) = (Ts+1)/K \ . \tag{17}$$

To achieve a smooth system, we add a filter in front of the IMC, which is set as follows: [9-16]

$$G_f(s) = \frac{1}{4.5s+1} \ . \tag{18}$$

The scanning step should be chosen to match the system, here we use λ =95. The lower part of the simulation model graph expresses the adaptive law implementation calculated from formula (15). The simulation results are as follows.

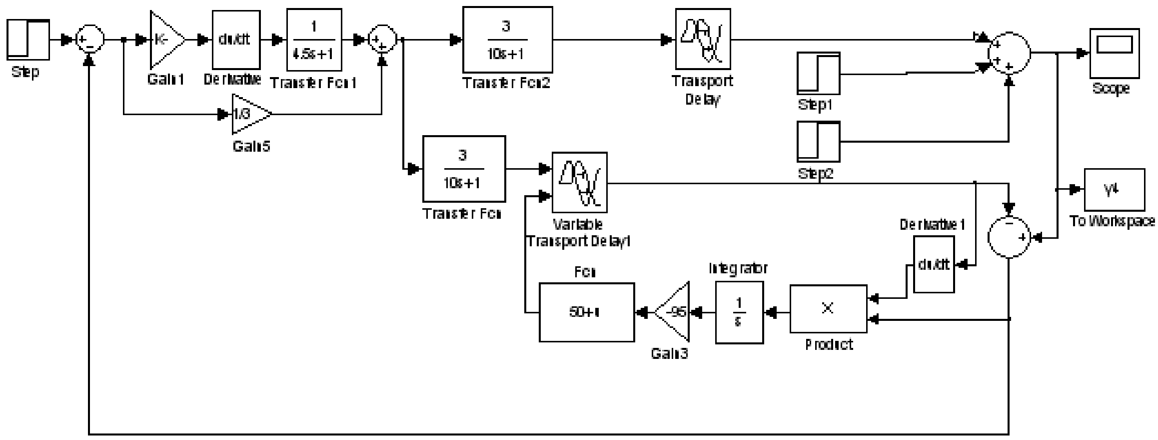

FIGURE 3 Adaptive IMC simulation model diagram

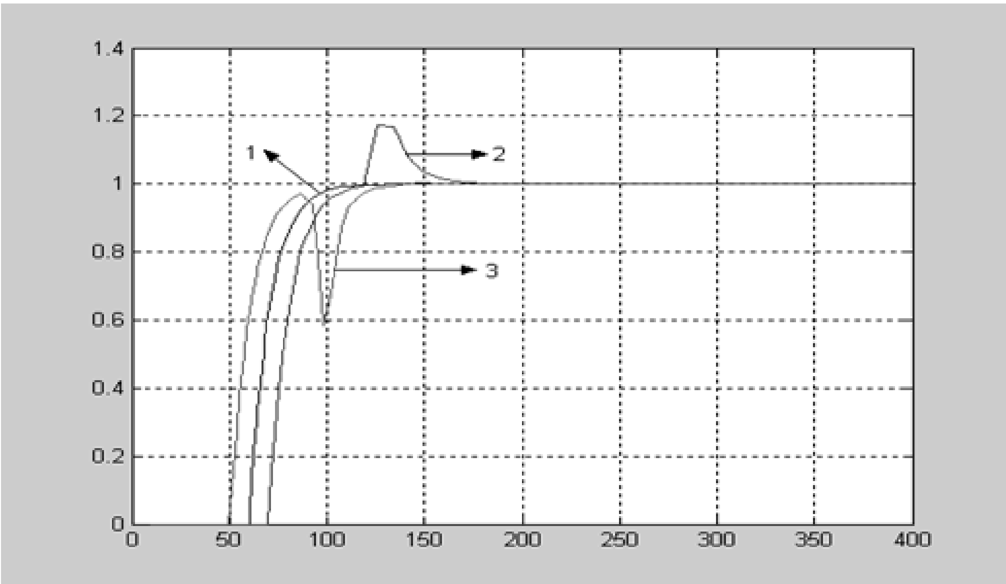

FIGURE 4 The simulation results of the adaptive IMC when the dead-time error is 20%

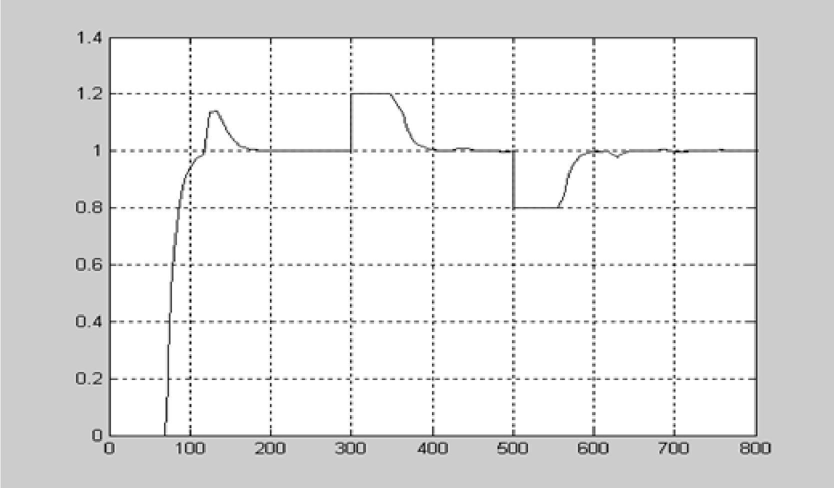

FIGURE 5 Adaptive IMC simulation results with dead-time and disturbance

Figure 4 displays the results of the designed adaptive IMC when the dead-time parameter is varying ±20%. Curve 1 is the adaptive IMC model simulation result after parameter adjustment; it has the advantages of no overshoot and static error when the model matches the object. Even when the dead-time is reduced by 20%, curve 2 shows an overshoot of approximately 20%. When the dead-time is increased by 20%, the overshoot is 40% as shown in curve 3, but both conditions achieve stability rapidly without static error.

Figure 5 is the result of the adaptive IMC with both dead-time and disturbance. The dead-time is firstly increased by 20%. At 300s, the disturbance is increased by 20% and at 500s, the disturbance is decreased by 20%. The simulation curve shows that the system becomes rapidly stable and displays almost no static error after the delay time.

As can be seen from the simulation results, the adaptive IMC can achieve stability after oscillation when the model dead time error is ±20%. The system can also achieve stability quickly under conditions of disturbance after the system's dead-time. Therefore, the designed adaptive IMC for variable parameters delay system has a suitable control effect.

4 Conclusions

In systems with large delays due to dead-time, the output signals in a conventional controller do not adjust fast enough to reflect the system's running conditions and therefore do not achieve a satisfactory control effect. The complexity and uncertainty of industrial processes causes frequent changes to object parameters; predictive control will not provide an adequate control effect in these situations, as it demands high model accuracy. This paper designs a model based on a first-order plus time delay adaptive law with local parameter optimization theory to identify the object parameters and modify the object online. The designed adaptive IMC model overcomes adverse effects that occur in the traditional IMC model due to inaccuracies, leading to improved controller performance, while maintaining the IMC characteristic of static error removal, ensuring that the system has good steady-state performance.

The simulation results show that the adaptive IMC has a low requirement for model accuracy, better robustness, good anti-interference ability and no steady-state error compared with conventional control methods. It is a superior control scheme for systems with variable parameters and a time delay.

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