Research Article

Discrete Model Reference Adaptive Control System for Automatic Profiling Machine

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Automatic profiling machine is a movement system that has a high degree of parameter variation and high frequency of transient process, and it requires an accurate control in time. In this paper, the discrete model reference adaptive control system of automatic profiling machine is discussed. Firstly, the model of automatic profiling machine is presented according to the parameters of DC motor. Then the design of the discrete model reference adaptive control is proposed, and the control rules are proven. The results of simulation show that adaptive control system has favorable dynamic performances.

1. Introduction

Automatic profiling machine is a movement system which has a high degree of parameter variation and high frequency of transient process, and it requires an accurate control in time. The traditional linear control methods, such as PID, cannot meet present needs or requirements of advanced performance. The adaptive control not only solves the problem that the control plant cannot be observed directly, but also improved the abilities of resisting interference [1]. The applications of adaptive control to movement system are widespread [2–4], but it is infrequent in automatic profiling machine. A practical adaptive controlling scheme is proposed for automatic profiling machine in [5]. In this paper, a discrete model reference adaptive control (MRAC) method is applied to automatic profiling machine. The discrete control method is convenient for program and contributes to application of adaptive control theory in practice.

2. The Mathematics Model

The control system is double closed-loop control system whose current loop is PI control and speed loop is MRAC. The DC motor parameters [6] of automatic profiling machine are shown in Table 1. The equivalent plant of speed

loop is consisted of current loop and motor, and the transfer function is

$$G(s) = \frac{2377011.5}{s^2 + 2252.87s + 5747.23}. \quad (1)$$

3. The Design of MRAC System

The difference equation of the plant is

$$A(z^{-1})y(k) = z^{-1}B(z^{-1})u(k), \quad (2)$$

where

$$A(z^{-1}) = 1 - \sum_{i=1}^n \hat{a}_i z^{-i}, \quad B(z^{-1}) = \sum_{i=0}^m \hat{b}_i z^{-i}, \quad (3)$$

$y(k)$ and $u(k)$ are the output and input of the plant, respectively; z^{-1} is delay operator; k is the discrete-time variable.

The difference equation of the reference model is

$$A_m(z^{-1})y_m(k) = z^{-1}B_m(z^{-1})r(k), \quad (4)$$

where

$$A_m(z^{-1}) = 1 - \sum_{i=1}^n a_i z^{-i}, \quad B_m(z^{-1}) = \sum_{i=0}^m b_i z^{-i}, \quad (5)$$

FIGURE 1: Block diagram of MRAC system.

TABLE 1: The parameters of DC motor.

Parameter	Unit	Value
Rated voltage	V	100
Rated current	A	6
Rated speed	r/min	1000
Motor constant	V/r/min	0.1
Electromagnetic time constant	s	0.00246
Mechanical time constant	s	0.078

$y_m(k)$ and $r(k)$ are the output and input of the reference model.

The output error and its prediction are given by

$$\begin{aligned} e(k) &= y(k) - y_m(k), \\ e^\circ(k) &= y^\circ(k) - y_m(k), \end{aligned} \quad (6)$$

where $e^\circ(k)$ and the other variables with “ $\circ$ ” represent the predictions.

The structure of the adaptive control system is shown in Figure 1 where

$$\begin{aligned} H(z^{-1}) &= \sum_{i=1}^n h_i(k) z^{-i+1}, \\ G(z^{-1}) &= \sum_{i=0}^m g_i(k) z^{-i}, \\ F(z^{-1}) &= \sum_{i=1}^n f_i(k) z^{-i+1}. \end{aligned} \quad (7)$$

From Figure 1, the following relationship can be obtained

$$B_m(z^{-1})r(k) = H(z^{-1})y_m(k) + F(z^{-1})e(k) + G(z^{-1})u(k). \quad (8)$$

Introduc (8) into (4):

$$\begin{aligned} A_m(z^{-1})y_m(k) \\ = z^{-1}[H(z^{-1})y_m(k) + F(z^{-1})e(k) + G(z^{-1})u(k)]. \end{aligned} \quad (9)$$

Subtract (9) from (2):

$$\begin{aligned} A(z^{-1})e(k) \\ = [A_m(z^{-1}) - A(z^{-1}) - z^{-1}H(z^{-1})]y_m(k) \\ + [z^{-1}B(z^{-1}) - z^{-1}G(z^{-1})]u(k) \\ - z^{-1}F(z^{-1})e(k). \end{aligned} \quad (10)$$

According to the Hyperstability theory, the discrete system control laws [1] are

$$\begin{aligned} h_i^I(k) &= h_i^I(k-1) + \lambda_i e(k) y_m(k-i), \\ h_i^P(k) &= \mu_i e(k) y_m(k-i), \end{aligned} \quad (11)$$

where

$$\begin{aligned} i &= 1, 2, \dots, n; \quad \lambda_i > 0; \quad \mu_i \geq -\frac{\lambda_i}{2}, \\ g_i^I(k) &= g_i^I(k-1) + \rho_i e(k) u(k-i-1), \\ g_i^P(k) &= \sigma_i e(k) u(k-i-1), \end{aligned} \quad (12)$$

where

$$\begin{aligned} i &= 1, 2, \dots, m; \quad \rho_i > 0; \quad \sigma_i \geq -\frac{\rho_i}{2}, \\ f_i^P(k) &= q_i e(k) e(k-i), \end{aligned} \quad (13)$$

$$f_i^I(k) = f_i^I(k-1) + l_i e(k) e(k-i),$$

where

$$i = 1, 2, \dots, n; \quad l_i > 0; \quad q_i \geq -\frac{l_i}{2}. \quad (14)$$

FIGURE 2: Simulation block diagram of MRAC system.

$E(k)$ cannot be found directly in the operations above, so it can be replaced by $e^\circ(k)$. According to (10), $e(k)$ becomes

$$e(k) = \sum_{i=1}^n [\hat{a}_i - f_i(k)] e(k-i) + \sum_{i=1}^n [a_i - a_i - h_i(\hat{k})] y_m(k-i) + \sum_{i=0}^m [\hat{b}_i - g_i(k)] u(k-i-1). \quad (15)$$

The prediction error can be gained:

$$e^\circ(k) = \sum_{i=1}^n [\hat{a}_i - f_i^I(k-1)] e(k-i) + \sum_{i=1}^n [a_i - a_i - h_i^I(\hat{k}-1)] y_m(k-i) + \sum_{i=0}^m [\hat{b}_i - g_i^I(k-1)] u(k-i-1). \quad (16)$$

Subtract (16) from (15) and link (11)~(13); the function becomes

$$e(k) - e^\circ(k) = - \left[\sum_{i=1}^n (l_i + q_i) e^2(k-i) + \sum_{i=0}^n (\lambda_i + \mu_i) y_m^2(k-i) + \sum_{i=0}^m (\rho_i + \sigma_i) u^2(k-i-1) \right] e(k). \quad (17)$$

Equation (17) becomes (18) by calculating,

$$e(k) = \frac{e^\circ(k)}{(1 + \sum_{i=1}^n (l_i + q_i) e^2(k-i) + \sum_{i=0}^n (\lambda_i + \mu_i) y_m^2(k-i) + \sum_{i=0}^m (\rho_i + \sigma_i) u^2(k-i-1))}. \quad (18)$$

4. Simulation Studies

The reference model takes the form as follows:

$$\frac{z^{-1} B_m(z^{-1})}{A_m(z^{-1})} = \frac{0.1475z^{-1} + 0.1451z^{-2}}{1 - 1.95z^{-1} + 0.9512z^{-2}}. \quad (19)$$

Make simulation according to the analysis above by SIMULINK. The structure of the adaptive control system is shown in Figure 2, and the parameters value are shown in Table 2.

The simulation results are shown in Figures 3–5. To make a calculation, the percentage overshoot is 6%, the rise time is 1 s, the settling time is 2 s ($\Delta = 0.02$). Figure 3 is shown that the maximal error value is less than 40 r/min, so the control plant could better track reference model. Input the interference signal into the front of plant transfer function between 10 s and 20 s. The simulation results (in Figure 4) indicate that the control plant could be stable in 2 seconds. Input white noise into the reference input of plant not the reference input of model, and the result is shown in Figure 5.

(a) Reference model

(a) Control plant

(b) Control plant

(b) Interference signal

(c) Error figure

(c) Error figure

FIGURE 3: Output figures of simulation.

FIGURE 4: Output figure with interference signal.

FIGURE 5: Output figures with white noise.

TABLE 2: Parameter values of MRAC system.

Parameter	Value	Parameter	Value
$h_1^I(0)$	0	$h_2^I(0)$	0
λ_1	0.1	λ_2	0.01
$g_1^I(0)$	1	$g_2^I(0)$	0
ρ_1	3000	ρ_2	0.01
$f_1^I(0)$	0	$f_2^I(0)$	0
l_1	1	l_2	0.1

Obviously the figure has no visible variation. So the control system has better abilities of resisting interference.

5. Conclusion

The discrete model reference adaptive control system of automatic profiling machine is discussed in this paper. The results of simulation show that adaptive control system has favorable dynamic performance. The discrete design method is easy to realize by computer. The work in this paper will lay a foundation for the application of adaptive control in practice.

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