Speed Control of DC Motor Using Fuzzy-Based Intelligent Model Reference Adaptive Control Scheme

Dayarnab Baidya and Rupam Gupta Roy

Abstract This investigation deals with the introduction of a noble dynamic fuzzy model reference adaptive control scheme. In this work, we propose a new model of MRAC using fuzzy control for the speed control of DC Motor. The starting of our work is done with the general comprehensive designing of MRAC for first-order process along with the second-order process using MIT Rule. After that, the description regarding our proposed model is given. For the evaluation of the performance of the controller, fuzzy-based MRAC is applied on DC Motor. The simulation results are compared with other controllers showing that the reaching time and tracking can be extensively reduced.

Keywords Adaptive control · Dynamic fuzzy model reference adaptive control scheme · MIT rule · Model reference adaptive control · PID controllers

1 Introduction

Adaptive control system is a special type of nonlinear control system which has the ability to vary its parameters for the adjustment to the variation in dynamics of the process or characteristics change in the disturbances. MRAC is one of the adaptive strategies where a reference model is used to adjust the controller parameters. Shyu (2008) and Stefanello (2008) applied the Lyapunov theory to develop the performance of shunt active power filter [1]. Suzuki et al. [2] designed MRACS with fuzzy adaptive control rules using genetic algorithm [2]. Wong et al. 3 designed indirect fuzzy adaptive controller for the controlling of unstable inverted pendulum [3]. Hwang (2000) and Tang (2001) proposed the concept of fuzzy PID controller. Lakhekar and Roy (2014) introduce the fuzzy neural approach for the dynamic

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spectrum allocation in cognitive radio networks and they contributed their efforts in developing dynamic fuzzy sliding mode control (DFSMC) for heading angle control of autonomous underwater vehicles (AUVs) in horizontal plane [4, 5].

In this article, we provide a detailed description regarding the general design procedure of the MRAC with the help of MIT Rule for the second-order process followed by our proposed model and apply it on DC motor for the control of speed. The Simulink results of different controllers are compared with the result obtained from the proposed model.

2 Design Procedure Using MIT Rule for Second-Order Process

In this case, a second-order process expressed by

$$\ddot{y} + p_1\dot{y} + p_0 y = qu \tag{1}$$

is selected and the process must follow the reference model which is given by

$$\ddot{y}_m + p_{1m}\dot{y}_m + p_{0m}y_m = q_m r \tag{2}$$

A particular control law is required to vary the reference input signal so that the plant's output signal track with the reference model [6]. This control law is time dependent upon controller parameters θ_1 and θ_2 which act as the adaptation to the given plant system. This control law is given by:

$$u = r\theta_1 - y_p\theta_2 \tag{3}$$

Substituting u in (1) using (3)

$$\ddot{y} + p_1\dot{y} + p_0 y = q(r\theta_1 - y\theta_2) \tag{4}$$

Taking the Laplace transform of (2) and (4) and then rearranging, we get

$$s^2Y(s) + (p_1 s + p_0 + q\theta_2)Y(s) = q\theta_1 R(s) \tag{5}$$

$$s^2Y(s) + p_{1m}Y_m(s) + p_{0m}Y_m(s) = q_m R(s) \tag{6}$$

The error (e) between the output of the reference model $(Y_m(s))$ and the process output (Y) is given as

$$E(s) = \frac{q\theta_1}{s^2 + p_1 s + p_0 s + q\theta_2} R(s) - Y_m(s) \tag{8}$$

Here, a cost function is selected as

$$\gamma(\theta) = \frac{1}{2}\ \mathrm{e}^2 \tag{9}$$

From the MIT Rule, it can be written [6]

$$\frac{\mathrm{d}\theta}{\mathrm{d}t} = -\alpha \frac{\partial \gamma}{\partial \theta} = -\alpha e \frac{\partial e}{\partial \theta} \tag{10}$$

where $\frac{\partial e}{\partial \theta}$ is called as the sensitivity derivative of the system.

Using (11) and partially differentiating (9) with respect to θ_1 and θ_2, we get

$$\frac{\partial E(s)}{\partial \theta_1} = \frac{q}{s^2 + p_1 s + p_0 + q\theta_2} R(s) \tag{11}$$

$$\frac{\partial E(s)}{\partial \theta_2} = -\frac{q}{s^2 + p_1 s + p_0 + q\theta_2} Y(s) \tag{12}$$

Now for the better performance of the plant, the reference model should be close to the plant. So (11) and (12) can be written from (8) as

$$\frac{\partial E(s)}{\partial \theta_1} = \frac{q}{s^2 + p_{1m} s + p_{0m}} R(s) \tag{13}$$

$$\frac{\partial E(s)}{\partial \theta_2} = \frac{q}{s^2 + p_{1m} s + p_{0m}} Y(s) \tag{14}$$

Inserting the following expressions of $\frac{\partial E(s)}{\partial \theta_1}$ and $\frac{\partial E(s)}{\partial \theta_2}$ in (10), it is obtained as

$$\frac{\mathrm{d}\theta_1}{\mathrm{d}t} = -\alpha \frac{q}{s^2 + p_{1m} s + p_{0m}} R(s) \tag{15}$$

$$\frac{\mathrm{d}\theta_2}{\mathrm{d}t} = \alpha \frac{q}{s^2 + p_{1m} s + p_{0m}} Y(s) \tag{16}$$

Equations (15) and (16) are the update laws for θ_1 and θ_2.

3 Dynamic Fuzzy Model Reference Adaptive Control (DFMRAC)

The basic design of model reference adaptive control is the initiation of the design procedure and selection of the adaptive control law in such a way that the necessities of the stability criterion are fulfilled. The main scheme of our approach is fuzzification of adaptive parameters. The parameters are fuzzified corresponding to the process input, error and output of the process. In our present work, we have used fuzzy controller in place of transfer function with the fact that fuzzy will take action for the adaptation of the plant with the variations in disturbances and surrounding conditions. The block diagram of proposed control scheme is shown in Fig. 1.

3.1 Takagi–Sugeno Fuzzy Inference System (TS-FIS)

The TS-FIS is a single-stage fuzzy system. The fuzzy inference systems are composed of a set of IF–THEN rules. A TS fuzzy model has the following form of fuzzy rules [7–9]:

$$R_k : \text{If } x_1 \text{ is } A_{1k} \text{ and } x_2 \text{ is } A_{2k} \ldots \text{ and } x_n \text{ is } A_{nk}$$

$$\text{Then } y = f_k(x_1, x_2, \ldots x_n), \; (k = 1, 2, \ldots N)$$

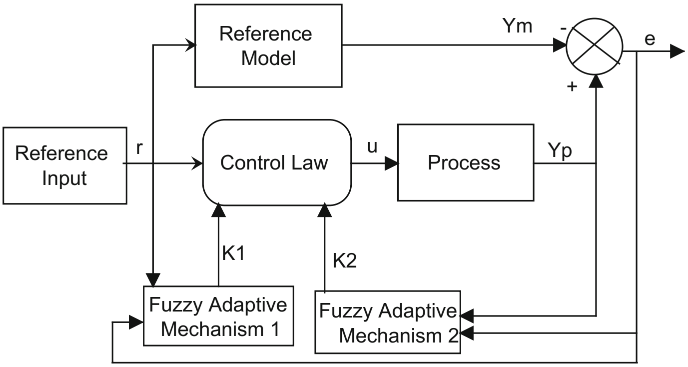

Fig. 1 Block diagram of dynamic fuzzy model reference adaptive control (DFMRAC)

where $f_k(.)$ is a crisp function of x_n. Normally, $f_k(x_1, x_2, \ldots x_n) = \rho_0 + \rho_1 x_1 + \rho_2 x_2 + \cdots + \rho_n x_n$. The final output of fuzzy system can be obtained as

$$y = \frac{\sum_{k=1}^{N} f_k(.) T_{i=1}^{r_k} \mu_{ik}(x_i)}{\sum_{k=1}^{N} T_{i=1}^{r_k} \mu_{ik}(x_i)} \tag{18}$$

where $1 < r_k < n$ is the number of input variables in the rule premise, N is the number of fuzzy rules, n is the number of inputs, μ_{ik} is the membership function for fuzzy set, and A_{ik} and T are a T-norm for fuzzy conjunction.

4 Simulation Results

The simulation study is done for DC motor speed control. The optimal simulation result is shown in Fig. 2. Here, we have compared the simulation results of fuzzy MRAC with other controllers. Fuzzy MRAC provides a better performance in both transient and steady-state response. Fuzzy MRAC has better dynamic response curve, shorter response time.

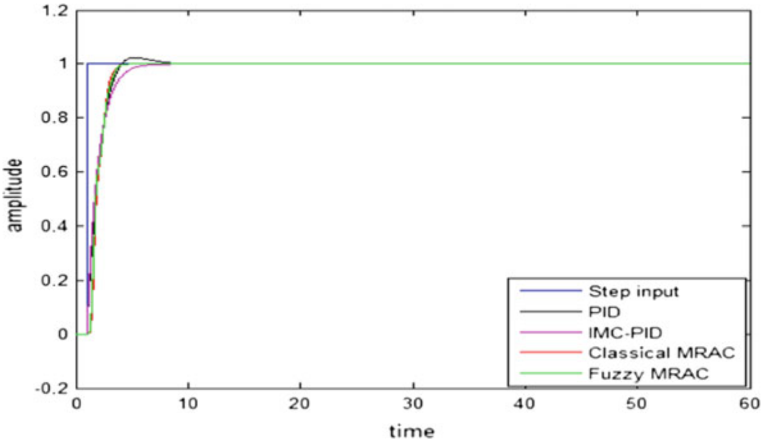

Fig. 2 Responses of DC motor under different controllers

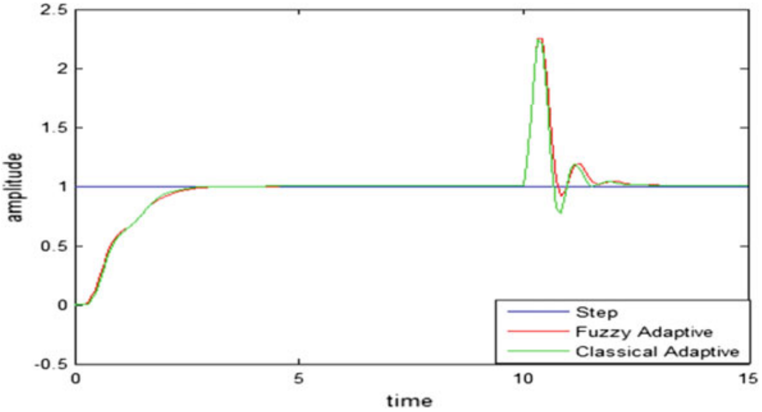

Fig. 3 Disturbance rejection response for step-type disturbance

5 Disturbance Rejection

A step-type disturbance is applied at time $t = 10$ s which is shown in Fig. 3. Oscillations of fuzzy adaptive control are less than classical adaptive control and fuzzy adaptive control settles faster. The robustness of the proposed controller is more than that of the classical adaptive control.

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