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Embedded two level direct adaptive fuzzy controller for DC motor speed control

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Abstract This paper presents a proposed approach based on an adaptive fuzzy logic controller for precise control of the DC motor speed. In this concern, the proposed Direct Adaptive Fuzzy Logic Controller (DAFLC) is estimated from two levels, where the lower level uses a Mamdani fuzzy controller and the upper level is an inverse model based on a Takagi–Sugeno (T–S) method in which its output is used to adapt the parameters of the fuzzy controller in the lower level. The proposed controller is implemented using an Arduino DUE kit. From the practical results, it is proved that the proposed adaptive controller improves, successfully both the performance response and the disturbance due to the load in the speed control of the DC motor.

1. Introduction

The permanent magnet direct current (PMDC) motor is an example of electromechanical systems with electrical and mechanical components. In this concern, this type of motors is commonly used in many industrial applications such as robot manipulators, home applications and sun trackers. Noting that, there are many classical and intelligent control techniques [1–5], such as PID, FLC, artificial neural networks, and many methods of AFLC are applied to control the speed of DC motor for achieving high performance. Classical mathematics and conventional control theory are very limited and difficult in modeling and controlling complex nonlinear dynamical systems [6,7]. On the other hand, fuzzy logic controller (FLC) is an alternative tool for PID controller [8,9], where the motivation for using fuzzy logic technology in control systems stems from the fact that it allows control designers to build a controller even when their understanding of the system is still in a vague and incomplete [10,11]. It provides a good tool for the control of nonlinear systems that are difficult in modeling [12,13]. But, the design of the FLC is not the optimum, where numerous difficulties appear to choose the controller parameters. Also, the presence of noise or any

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changes in the plant parameters, the controller may not be able to achieve adequate performance level. Finally, an adaptive controller is one of the controllers that adjust itself to reach adequate performance [14–16]. In this concern, the main contribution of the present study is the success of the proposed controller to be implemented on the Arduino DUE board to control the speed of DC motor using a proposed DAFLC which uses Takagi–Sugeno (T–S) fuzzy system in the second level to minimize the effects of the system's load disturbance.

In the present paper, two-level fuzzy controller (TLFC) is presented to control and improve the speed of DC motor. In general, it is considered as an adaptive fuzzy control, where DAFLC can be adjusted directly with a reference model. This design is implemented on Arduino DUE kit, applying Arduino 1.5.5-r2 software. Finally, the organization of the paper is as follows: Section 2 describes the structure and the design of the fuzzy PI controller, and the DAFLC is explained in Section 3. The Arduino implementation is explained in Section 4. Results and discussions are presented in Section 5. Finally, conclusion is in the last section.

2. Fuzzy PI controller design

FLC enables control designers to design and build the controller by forming IF–THEN rules which are in the form of statements [12,17]. The structure of FLC contains four main parts [14,15] as shown in Fig. 1: Fuzzification, inference mechanism, rule base and defuzzification, where fuzzification part is used for converting real input to fuzzy input. The rule-base part contains the expert knowledge in the form of a set of rules. The inference mechanism part evaluates which control rules are relevant at the current time and then decides what the input to process should be and defuzzification part is opposite fuzzification, where it is used for converting fuzzy output to real output. There are two inputs and one output, where the first input is error (e) which is the difference between reference speed of the motor (W_{ref}) and its actual speed of motor (W_{act}). The second input is the change of error (Ce) which is defined as the difference between the present error $e(k)$ and the previous error $e(k-1)$ given by Eqs. (1) and (2), respectively, where, k is the sampling instance. On the other hand, the output is the change of control signal (ΔU). For getting control signal (u), Eq. (3) is applied, as shown in Fig. 2 as follows:

$$e(k) = W_{ref} - W_{act} \tag{1}$$

$$\mathrm{Ce}(k) = e(k) - e(k-1) \tag{2}$$

$$u(k) = u(k-1) + \Delta U(k) \tag{3}$$

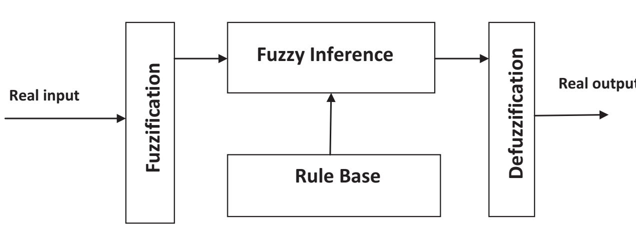

Figure 1 Structure of fuzzy logic controller.

For each of the two inputs and output, there are seven fuzzy sets on universes with linguistic values; namely: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). The motor range of speed is very large, so the error and change of error ranges are very high, as it is difficult to handle with large values. The universe of discourse for input and output is normalized value from −6 to 6, where we can use gains G1, G2 and G3 for two inputs and output universe of discourse respectively [18] as shown in Fig. 2. The designers can choose many different shapes based on their preference and experience [17]. These are characterized by the Gaussian membership and are shown in Fig. 3 where, in general the mathematical expression for Gaussian function is

$$\mu(x) = \exp\left(-\frac{1}{2}\left(\frac{x-c}{\sigma}\right)^2\right) \tag{4}$$

where
c: the center of membership function and
$\sigma > 0$: determines the spread or width of the function.

Mamdani type rule base structure is used in this controller; there are 49 rule bases, as given in Table 1. To evaluate the value of the rule antecedents, one should use the *AND* operator (minimum). But, if a given fuzzy rule has multiple consequent, the *OR* fuzzy operator (maximum) is used to obtain a single number that represents the result of the consequent evaluation [19]. Finally, many defuzzification methods can be used for leading defuzzification [20]. Finally, weighted average method (Eq. (5)), is proposed to be applied throughout the present work. The matter is due to that it is characterized by its simple calculations and easy for implementation on Arduino (kit/board). From which, and after compensation of the ΔU value into Eq. (3), one can easily get the control signal u (duty cycle). Hence, this result is transferred to the DC motor.

$$\Delta U = \frac{\sum_i^n \mu_i(\Delta U_i)\cdot c_i}{\sum_i^n \mu_i(\Delta U_i)} \tag{5}$$

where
$\mu_i(\Delta U_i)$: values of membership function (MF) for output, and
c_i: values of output MF centers.

3. Direct Adaptive Fuzzy Logic Controller (DAFLC)

DAFLC is called a fuzzy model reference learning controller (FMRLC). The functional block diagram for the FMRLC [14,21] is shown in Fig. 4. Basically, it consists of four main parts: the plant, fuzzy controller to be tuned, the reference model, and the learning mechanism block (an adaptation mechanism). Mainly, the fuzzy control system loop (the lower level of Fig. 4) operates to make "$W_{act}(kT)$" track "$W_{ref}(kT)$" by manipulating $u(kT)$, while the upper level adaptation control loop which uses Takagi–Sugeno (T–S) fuzzy controller as an inverse model (the upper level of Fig. 4) seeks to make the output of the plant $W_{act}(kT)$ track the output of the reference model "Wm(kT)" by manipulating the fuzzy controller parameters. FLC is explained in Section 2 and we will describe the other parts of DAFLC.