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Adaptive PID-Type Iterative Learning Control for DC Motor Position

Tri-Quang Le
Dept. Automobile Engineering
Hung Yen University of Technology and Education
Hung Yen, Vietnam
quangletri@gmail.com

Nguyen Ngoc Tu
Dept. Automobile Engineering
Hung Yen University of Technology and Education
Hung Yen, Vietnam
nguyenngoctuuct@gmail.com

Le Ngoc Truc
Dept. Automobile Engineering
Hung Yen University of Technology and Education
Hung Yen, Vietnam
lengoctruc@gmail.com

***Abstract*—The paper aims to control the DC motor position. The proposed method is adaptive PID-type iterative learning control based on fuzzy logic. The Developed processor-in-the-loop simulation based on Simulink and Arduino Mega 2560 demonstrated the high performance of the proposed solution.**

***Index Terms*—PID, ILC, DC motor, Adaptive control**

Introduction

DC motor has many advantages, such as being inexpensive, reliable, and giving high torque at a low speed [1]. Moreover, it is robust control for both speed and position. Hence, it widely applies, for example, the electric vehicles, sheets, mirrors, etc., enhancing the control accuracy of the position and speed of the DC motor are two aspects that attract many researchers worldwide. Chotai [2] applied the linear control methods (PID and LQR) to control the speed of the DC motor. The conventional PID instances three terms: proportional, integral, and derivation. The controller output is the sum of these terms based on the error information. PID has many advantages as simply an algorithm and guarantees satisfactory performance. The limitation of PID, the value of control gain (Kp, Ki, Kd), constantly leads to reduced control quality in the vast range of operations, especially in nonlinear under-actuated systems [3]. LQR is a type of linear optimal control; its quality depends on the accuracy of the system model and the value of the weight matrices Q and R.

The linear control method cannot be well handled since DC motors operate in disturbances and uncertain conditions. So the nonlinear control method, such as backstepping, and sliding mode control, is used against the influence of external disturbance. An excellent control method is the robust adaptive backstepping proposed by Roy, T. K., et al. [4] for controlling the speed of a series DC motor. Finally, it is intelligent methods that overcome uncertainty problems well compared with others. Primarily, it can maintain high performance at a wide range of operations, for example, fuzzy control algorithm [6-8]; RBF neural network and Genetic algorithm [9]; and iterative learning control [10,11].

This paper is the first step in developing an autonomous steering system for a small self-develop electric car using a DC motor. The adaptive PID-type iterative learning control is a proposed method. In which fuzzy logic was used for adjusting the value of control factors (Kp, Kd) corresponding to the amount of the error and change of error. In combination with repeated work of the controller, the static error was minimally reduced, leading to the total system quality improvement. Simulation results were verified on the developed processor-in-the-loop (PIL) simulation based on Arduino Mega 2560 and MATLAB Simulink.

The rest of the paper includes sections: section 2 presents the modeling of the DC motor; section 3 represents the proposed method; section 4 is experiment results and discussions; Finally, conclusions are presented in section 5.

Modeling of DC Motor

Figure 1 presents the principle circuit of the DC motor. Some physical parameters can be defined as follows. J denotes the moment of inertia of the rotor; b stands for viscous motor friction constant. Kb, Kt, and R mean electromotive force constant, motor torque constant, and electric resistance, respectively. Finally, L is the electric inductance.

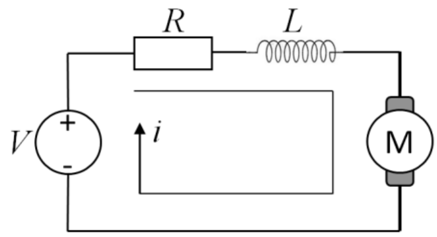

Fig. 1. Principle diagram of DC motor

The electric torque

$$T = K_t * i(\tau) \tag{1}$$

$$e(t) = K_b * \dot{\theta} \tag{2}$$

Assume the torque constant is equal back emf constant

$$K_t = K_e = K \tag{3}$$

Applying Kirchoff's and Newton's 2nd law

$$J\ddot{\theta} + b\dot{\theta} = Ki(t) \tag{4}$$

$$U(t) - K\dot{\theta} = i(t) * R + L\frac{di(t)}{dt} \quad (5)$$

Convert equations (4)(5) to Laplace domain

$$s(Js + b) = KI(s) \quad (6)$$

$$(Ls + R)I(s) = V(s) - Ks\Phi(s) \quad (7)$$

From equations (6)(7), the transfer function of speed and voltage

$$\frac{\dot{\Phi}(s)}{V(s)} = \frac{\omega(s)}{V(s)} = \frac{K}{(Js + b)(Ls + R) + K^2} \quad (8)$$

Because the position is speed integration, so transfer function of position and voltage has formed as equation (9)

$$\frac{\Phi(s)}{V(s)} = \frac{K}{s[(Js + b)(Ls + R) + K^2]} \quad (9)$$

$$\frac{\Phi(s)}{V(s)} = \frac{0.04612}{0.0004448s^2 + 0.002078s + 0.002142} \quad (10)$$

The parameter estimation toolbox was used to predict parameters J, b, L, R, and K, estimation values as shown in Table 1. The final transfer function was presented in equation 10. And figure 2 describes the processing determination parameter of the DC motor.

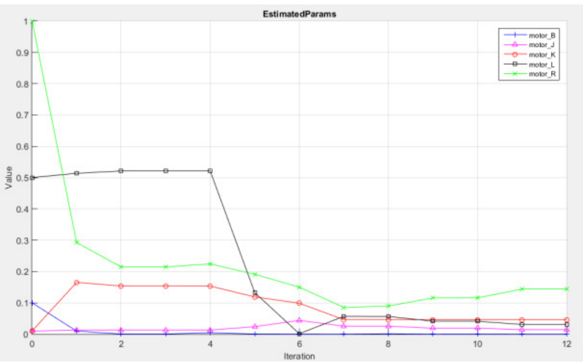

Fig. 2. Results of the estimation of the DC motor parameters

TABLE I. ESTIMATION PARAMETERS OF THE DC MOTOR

Estima tion	The symbols				
	J	*b*	*K*	*R*	*L*
Value	0.014393	0.00010516	0.046115	0.14412	0.030905

CONTROL APPROACH

A. *PIL structure*

Figure 3,4 presents the PIL structure and diagram of the connected circuit: the Laptop installed MATLAB&Simulink, Arduino Mega 2560, power bridge circuit L298N, and the DC motor attached encoder.

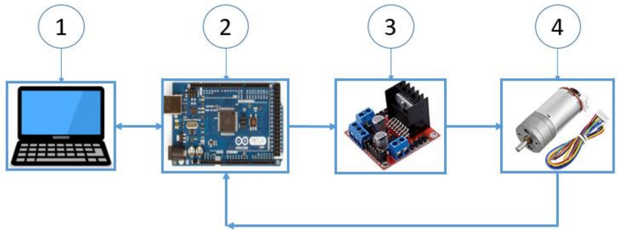

Fig. 3. Block diagram of PIL simulation

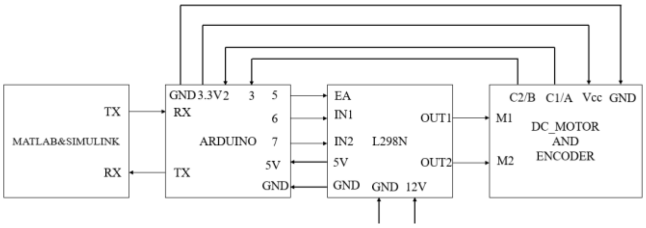

Fig. 4. Diagram of wire connection

The control program was developed in MATLAB&Simulink installed on Laptop. Arduino Mega 2560 is considered a data acquisition device. Communication between Arduino and Simulink is via a USB port. Three control signals sent from pins 5,6,7 to three-pin EA, IN1, and IN2 control motor speed and rotation direction. The encoder sends the motor position signal to Arduino, then compares it with the desired value to determine the error.

B. *Control approaches*

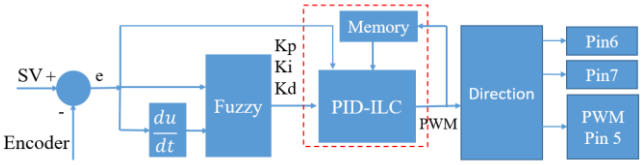

Fig. 5. Block diagram of the proposed control approach

Figure 5 illustrates the block diagram of the developed controller, called adaptive PID-type iterative learning control. Fuzzy logic adjusts PID control gain (Kp, Ki, Kd) corresponding to the amount of the error and change of error. And the block of direction controls DC motor rotation direction via Pin 6, 7. And Pin 5 controls motor speed.

1. *Fuzzy logic controller*

Used fuzzy logic is Sugeno type, which has two input and two output signals, showed figure 6. K1, K2, and K3 are scale factors. In order to fuzzify the input variables, fuzzy sets are used as follows:

e = {NB, NS, Z, PS,PB}

de = { NB, NS, Z, PS,PB}

Kd = { NB, NS, Z, PS,PB }

Kd = { Z, PS,PB}

Linguistic variables have the meaning as follows: negative (N), positive (P), zero (Z), small (S), and big (B). And the membership function and fuzzy rules are presented in figure 7-10, respectively. And figure 11 and 12 present adaptive PID control factor (Kd, Kp), respectively.

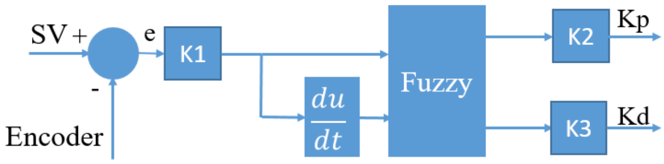

Fig. 6. Block diagram of fuzzy logic controller

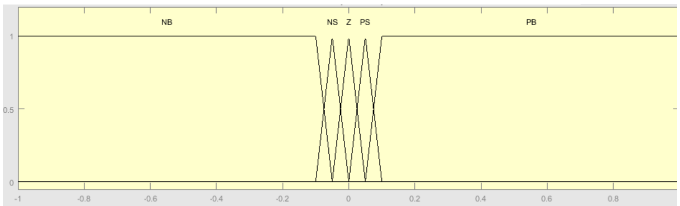

Fig. 7. Membership function of the error

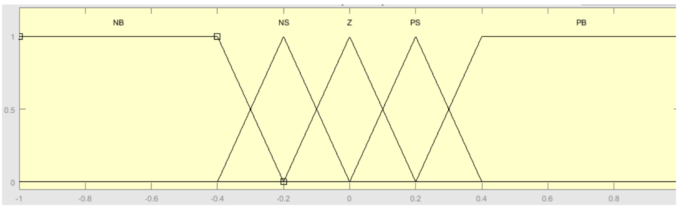

Fig. 8. Membership function of the change of error

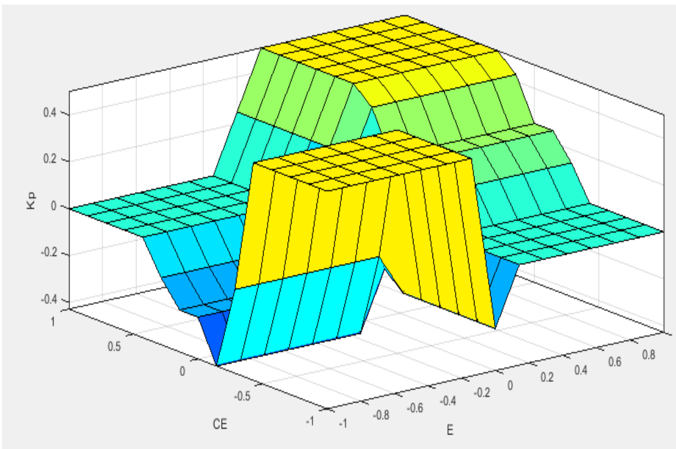

Fig. 9. Surface rules of Kp gain

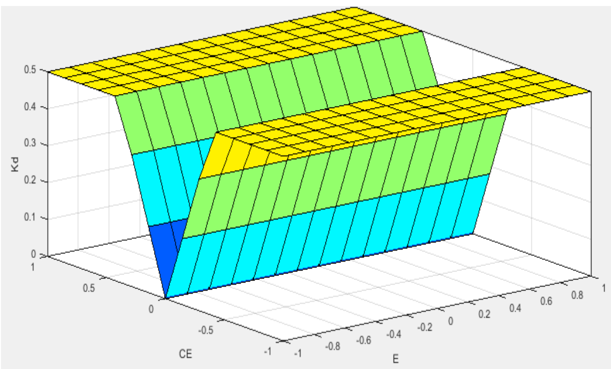

Fig. 10. Surface rules of Kd gain

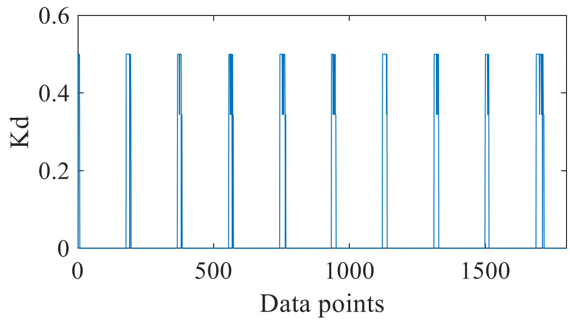

Fig. 11. Change of Kd

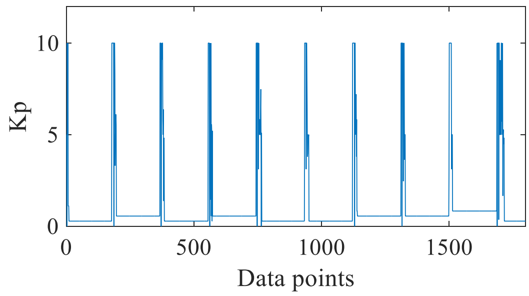

Fig. 12. Change of Kp

2. *PD-type iterative learning control*

Iterative learning control (ILC) operates based on repeated tasks, which was proposed by Arimoto et al. [12], updated law given in equation (11). Where Φ, Γ, ψ are learning gain matrices. ILC structure is presented in figure 13

$$u_{k+1} = u_k + \Phi e_k + \Gamma \dot{e}_k + \Psi \int e_k dt \qquad (11)$$

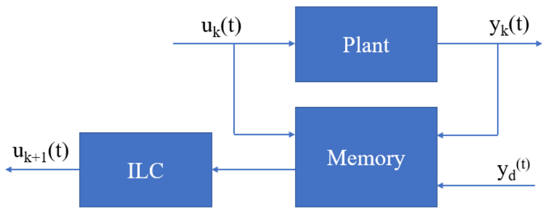

Fig. 13. Structure of the iterative learning control

Processor-In-The-Loop Simulation Results and Discussions

Two scenarios, sinusoidal and square signal, were used for verification of the proposed method., figure 14, 15. PID and the proposed controller gave excellent results, with a well-tracking reality signal and a minor error. In the sinusoidal, the current method is more oscillation than PID. It is caused by the reference signal constantly changing. So control signals generated by ILC, the sum of the current and previous control signals, also constantly change to keep the real value fitting the target value. Whereas, in case the target signal has a square form. The developed controller gave better results than PID. The static error was eliminated. It also demonstrates that ILC is more suitable for eliminating static error at a stable state for tracking control tasks.

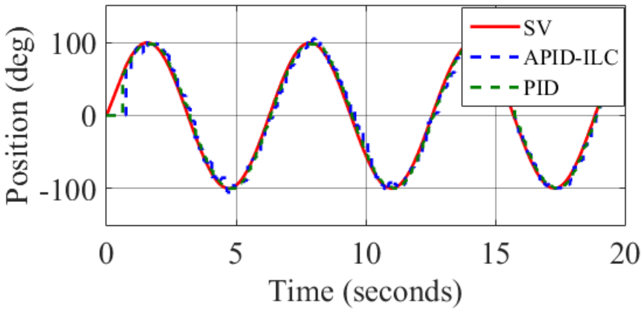

Fig. 14. PIL simulation results for the sinusoidal signal

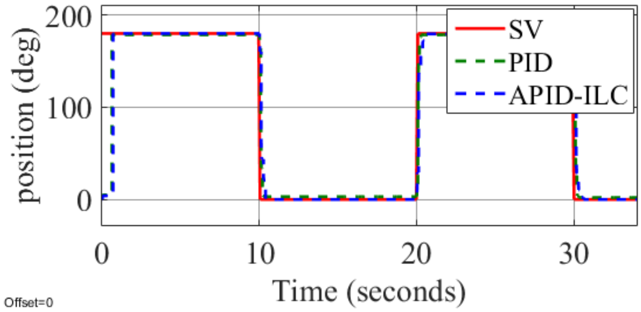

Fig. 15. PIL simulation results for the square signal

Conclusions

This paper proposed adaptive PID-type iterative learning to control DC motor position. The PIL simulation results demonstrated the high quality of the developed controller when compared with the traditional PID. In the future, we will apply the current method for the steering system on the self-developed electric car.

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