ADAPTIVE FUZZY LOGIC CONTROL OF DC MOTORS WITH NONLINEAR FRICTION

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Abstract

This paper presents an application of an adaptive fuzzy logic controller (AFLC) for a DC motor system with nonlinear friction. The developed AFLC ensures that: 1) the close-loop system is globally stable and 2) the tracking error converges to zero asymptotically and a cost function is minimized. The simulation results show that the proposed AFLC operates well and provides good quality of the control system.

1. INTRODUCTION

The high-quality servos are largely described by nonlinear models. Their performance is often limited by nonlinear phenomena such as friction and backlash. Therefore, we consider a problem of this type, namely, a servo with nonlinear friction, which causes difficulties and gives rise to poor performance in precision servos.

Friction compensation has been considered before. In order to address better the demands of high fidelity control, adaptive friction compensation algorithms have recently appeared in the literature. The use of a recursive least-squares algorithm to estimate the parameters in a nonlinear friction model was described by Canudas et al. [1]. Friedland and Park [2] presented another adaptive friction compensation scheme which was based upon a Lyapunov-like argument involving the position error. Many other studies on friction compensation are reported in a survey paper [3]. However, these methods are based on the characteristics of the nonlinearity and knowledge of some of the parameters, in contrast to the adaptive methods considered here.

Recently, advances in the area of artificial neural networks have provided the potential for new approaches to the control of nonlinear systems through learning process. Relevant features of the neural networks in the control context include their ability to model arbitrary differential nonlinear functions, and their intrinsic on-line adaptation and learning capabilities. Narenda and Parthasaraty [4] have shown by the simulations that the neural networks can be used effectively for the identification and control of nonlinear dynamic processes. In robotics, Kawato et al. [5] used an hierarchical neural network model as add-on component to the conventional linear controller in order to control the movement of a robot. Lewis et al. [6] proposed a multilayer neural-net robot controller with guaranteed tracking performance. Jang J.O. and Jeon G.J. [7] proposed a neural network control method of compensation of the nonlinear friction. The neural-network controller consists of a linear controller in parallel, which is employed to compensate for nonlinear friction effects. The proposed neural network control method has been implemented on a DC motor system.

In this paper, we propose an adaptive fuzzy logic controller (AFLC) for nonlinear dynamic systems. The proposed AFLC consists of a simple fuzzy logic controller and an adaptive law, which adjusts the free parameters of the controller for the purpose of controlling plant to track a reference trajectory. The adaptive fuzzy logic control method has been implemented on a DC motor system with nonlinear friction.

This paper is organized as follows. The proposed structure scheme of AFLC for DC motor with friction is presented in section 2. The adaptive fuzzy logic control method is described in section 3. Simulation results are shown in section 4. Some conclusions are given in section 5.

2. DESCRIPTION OF ADAPTIVE FUZZY LOGIC CONTROL SYSTEM

The overall scheme of adaptive fuzzy logic control system, which is considered in this paper, is shown in Fig.1. A DC motor with a permanent magnet was used in our control system. Such a motor is used in robots and precision servos. The motor with nonlinear friction can be described by the following model:

$$\begin{aligned} \dot{x}_1 &= -\frac{1}{T_m}x_1 + \frac{k_m}{T_m}\left[x_2 - M_d - F(x_1)\right] \\ \dot{x}_2 &= -\frac{1}{T_e}x_2 + \frac{k_e}{T_e}u \ , \end{aligned} \tag{1}$$

where $x_1 = \omega$ is the velocity of the motor shaft, M_d is the load disturbance, k_e and k_m are the gains, T_e and T_m are the time coefficients. The friction model is [7]:

$$\begin{aligned} M_f &= F(\omega) \\ &= \alpha_0 \operatorname{sgn}(\omega) + \alpha_1 \exp(-\alpha_2|\omega|)\operatorname{sgn}(\omega) \end{aligned} \tag{2}$$

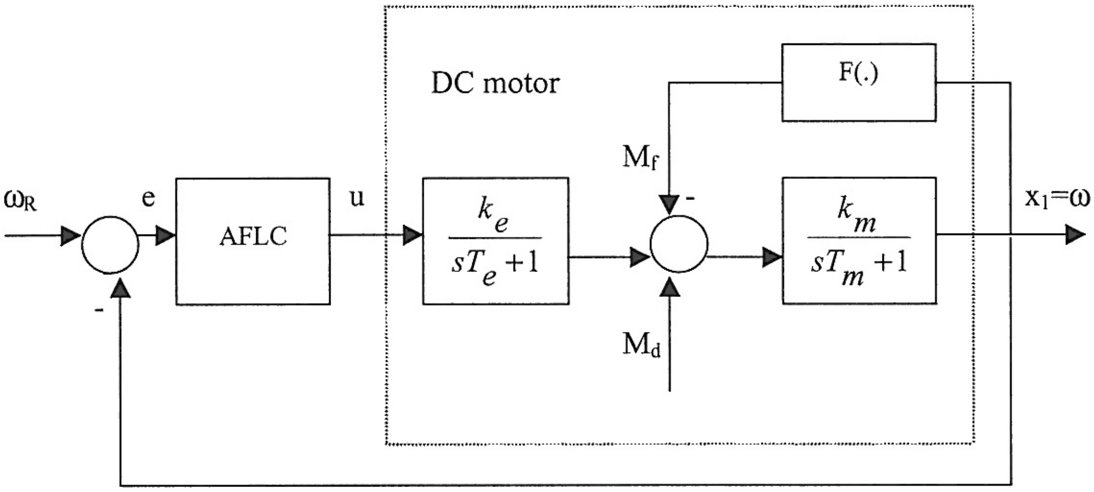

Fig.1. The overall scheme of adaptive fuzzy logic control system

3. AN ADAPTIVE FUZZY LOGIC CONTROLLER FOR THE DC MOTOR SYSTEM

In this section, we first setup the control objectives and show how to develop an AFLC to achieve them.

Control objectives. Determine a feed back control $u = u(\underline{e}, \underline{\lambda})$ (based on fuzzy logic system) and an adaptive law for adjusting the parameter vector $\underline{\lambda}$ such that the following conditions are met:

a) the close-loop system must be stable;

b) $\lim_{t \to \infty} |\omega_R - \omega| = \lim_{t \to \infty} |e| = 0$, where ω_R is the reference velocity of the motor shaft;

c) the coat function $J = \int_0^\infty \left(\Psi^2 + \dot{\Psi}^2 \right) dt$

is minimized, where $\Psi = e + k\dot{e}$.

The conditions a), b) and c) can be ensured by applying the following simple fuzzy logic control:

$$u(\underline{e}, \underline{\lambda}) = \frac{\sum_{j=1}^{L} \lambda^j \mu_{A_1^j}(e) \mu_{A_2^j}\left(\dot{e}\right)}{\sum_{j=1}^{L} \mu_{A_1^j}(e) \mu_{A_2^j}\left(\dot{e}\right)} = \underline{\lambda}^T \underline{\zeta}(\underline{e}), \tag{3}$$

where $A_i^j, i = \overline{1,2}$ are the input linguistic variables, $\mu_{A_i^j}$ is input membership function, L is the number of fuzzy logic control rules, $\underline{\lambda}^T = \left[\lambda^1, \lambda^2, ..., \lambda^L\right]$ are updated using the adaptation law [9]:

$$\dot{\underline{\lambda}} = \gamma \left(e + k\dot{e} \right) \underline{\zeta}(\underline{e}) \tag{4}$$

where γ is the positive constant determining the speed of the algorithm, k is the positive constant determining quality of the control system.

We simply summarize the method based on (3) and (4) by following these steps:

Step 1. Fuzzy logic controller construction

- Define fuzzy sets A_i^j, $i = \overline{1,2}$, $j = \overline{1,L}$, where L is the number of rules.
- Define membership functions $\mu_{A_i^j}$.
- Construct control signal by form of (3).

Step 2. On-line adaptation

- Apply the feedback control (3) to the plant (1).
- Use the adaptive law (4) to adjust the parameter vector $\underline{\lambda}$.

4. SIMULATIONS

In this section, we apply the AFLC developed in this paper to control the DC motor with nonlinear friction. The computer simulation of control system is done by the language MATLAB.

The simulation result of the DC motor with AFLC is shown in Fig.2, in which we can see that the developed AFLC could achieve the reference velocity of DC motor.

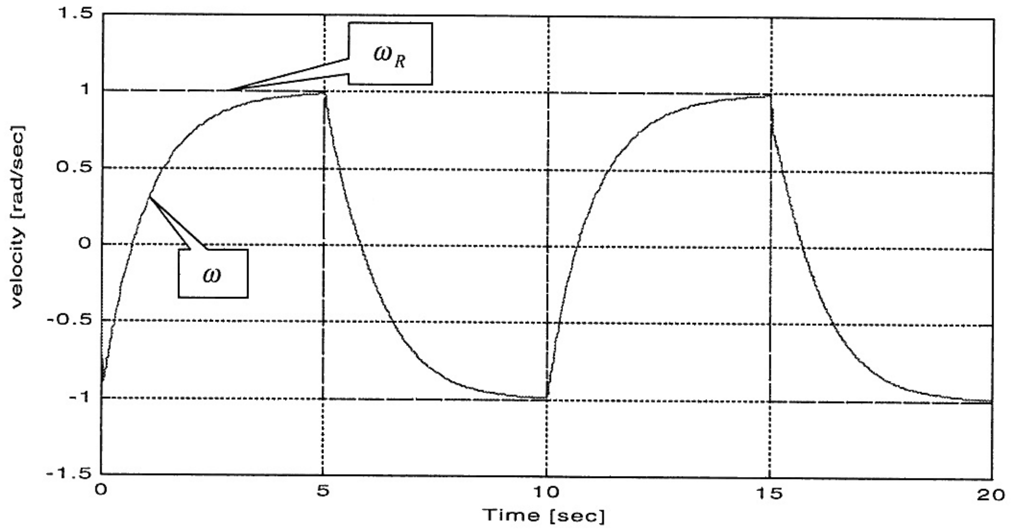

Fig.2. The reference and real velocity of DC motor

We also investigate the motor velocity with the sinusoidal reference signal. The simulation results appear in Fig.3. The response of the control system, where the load is changed, is shown in Fig.4. From this we can see that the AFLC achieves good trajectory.

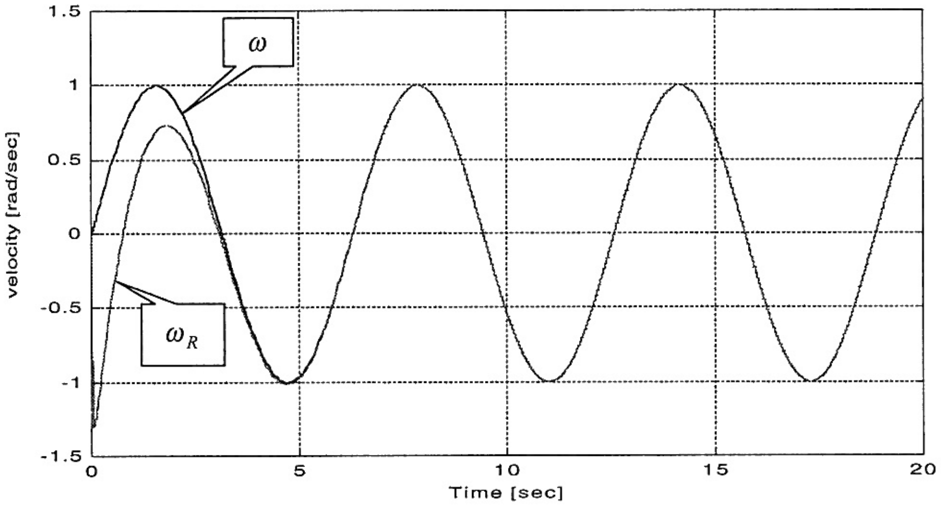

Fig.3. The reference and real velocity of DC motor

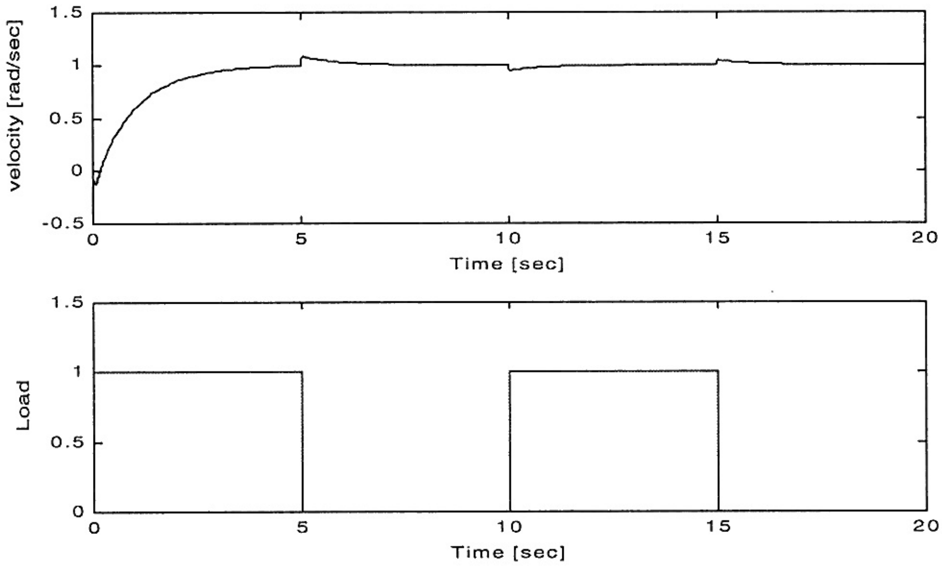

Fig.4. The velocity of DC motor and load

5. CONCLUSION

In this paper, we have developed an adaptive fuzzy logic controller for a DC motor system with nonlinear friction. The developed AFLC ensures that: 1) the close-loop system is globally stable and 2) the tracking error converges to zero asymptotically and a cost function is minimized. The simulation results show that the proposed AFLC operates well and provides good quality of the control system.

6. REFERENCES

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