순환형 퍼지-신경망과 강인한 마찰 상태관측기를 이용한 동적 마찰시스템의 위치제어

Position Control on the Dynamic Friction System Using Friction State and Recurrent Fuzzy-Neural Network

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1. Introduction

A nonlinear friction is an unavoidable phenomenon appeared in mechanical system between two contact surfaces. Specially, in the low velocity range, the effects of the friction on the performance of the servo system are more greater than moderate velocity range since the friction forces/torques coming from the stick and pre-sliding motion are dominant than control input forces/torques

Canudas de Wit et al[1], presented a dynamic friction model, called as LuGre friction model, which captures both dynamic friction of low velocity and steady state friction characteristic. However, the state representing the bristle deformations of the LuGre friction model cannot be measured directly, the estimation process for it must be presented to obtain more precise information on the friction dynamic. In addition, the parameter variations and unmodeled disturbances can deteriorate the performance of the control system due to the model-based property of the control system. Thus, the robust controller to overcome the modeling error and parameter variations must be designed to obtain the precise tracking performance. The approximation on these uncertainties of the system can be done well by the fuzzy or neural networks scheme.

Recently, the recurrent FNN (RFNN)[2] has been developed. The RFNN is a dynamic mapping and demonstrates good control performance in the presence of uncertainty such as parameter variations of the system, external load, unmodeled dynamics compared to the feedforward FNN.

In this paper, we propose the hybrid friction control system comprised of the sliding mode controller, the robust dynamic friction state observer, the RFNN and the error estimator. The friction state observer can estimate the immeasurable internal friction state of the LuGre friction model. In addition, the RFNN is introduced to approximate the uncertainty and the adaptive robust estimator for the approximation error is also designed. The mechanical servo system assembled with ball-screw and DC servo motor is chosen to demonstrate the good performance of the proposed control scheme through the simulation and experiment.

2. Design the controller and friction observer

The dynamic model for the mechanical system in the presence of friction is

$$J\ddot{q} + \sigma_2\dot{q} + T_f + T_d = u \tag{1}$$

The average defection of the elastic bristle is

$$\dot{z} = \dot{q} - f(\dot{q})z \tag{2}$$

$$f(\dot{q}) = \frac{|\dot{q}|}{g(\dot{q})} \tag{3}$$

$$\sigma_0 g(\dot{q}) = T_c + (T_s - T_c)e^{-(\dot{q}/\dot{q}_s)^i} \tag{4}$$

$$T_f = \Phi(\dot{q})z + \sigma_1\dot{q} \tag{5}$$

$$\Phi(\dot{q}) = \sigma_0 - \sigma_1 f(\dot{q}) \tag{6}$$

$$J\ddot{q} + \sigma_3\dot{q} + T_z + T_d = u \tag{7}$$

where $T_z = \Phi(\dot{q})z$ .We define the sliding surface as follows:

$$s = \dot{e} + c_1 e + c_2\int e\,dt \tag{8}$$

$$e = q_d - q \tag{9}$$

The control input is chosen as

$$u_{RFNR} = J(c_1\dot{e} + \ddot{q}_d + c_2 e) + \sigma_3\dot{q} + \beta s + \hat{T}_z + \hat{T}_d + \hat{U} \tag{10}$$

Substituting Eq. (10) into Eq. (7), the sliding surface is

$$\dot{s} = \frac{1}{J}(\Phi(\dot{q})\tilde{z} - \beta s + \tilde{U}) \tag{11}$$

The friction state observer is proposed as

$$\hat{z} = w + \frac{J}{\sigma_1}s + k_1 e \tag{12}$$

$$\dot{w} = \frac{1}{\sigma_1}[-\sigma_0 w - \sigma_2\dot{q} - J\frac{\sigma_0}{\sigma_1}s + u_{RFNR}$$

$$+\Phi(\dot{q})s - \sigma_0 k_1 e - J(\ddot{q}_d + c_1\dot{e} + c_2 e) - \hat{T}_d - \hat{U}] - k_1\dot{e} \tag{13}$$

Let us define the Lyapunov function as follows:

$$V_1 = \frac{1}{2}Js^2 + \frac{1}{2}\sigma_1\tilde{z}^2 + \frac{1}{2\eta}\tilde{U}^2 \tag{14}$$

The time derivative of Eq. (14) is

$$\dot{V}_1 = s[\Phi(\dot{q})\tilde{z} - \beta s + \tilde{U}] + \sigma_1\tilde{z}\dot{\tilde{z}} + \frac{1}{\eta}\tilde{U}\dot{\tilde{U}}$$

$$= s[\Phi(\dot{q})\tilde{z} - \beta s + \tilde{U}] + \sigma_1\tilde{z}(\dot{z} + \dot{\hat{z}}) + \frac{1}{\eta}\tilde{U}(-\dot{\hat{U}})$$

$$= -\beta s^2 - \sigma_0\tilde{z}^2 - \tilde{z}\tilde{U} + \tilde{U}(s - \frac{1}{\eta}\dot{\hat{U}}) \tag{15}$$

The adaptive robust estimation law for the estimate of uncertainty approximation error is chosen by

$$\dot{\hat{U}} = \eta\cdot s \tag{16}$$

Then, Eq. (15) is written as

$$\dot{V}_1 = -\beta s^2 - \sigma_0\tilde{z}^2 - \tilde{z}\tilde{U} \le -\sigma_0\tilde{z}^2 - \tilde{z}\tilde{U} = -\boldsymbol{Z}^T\boldsymbol{M}\boldsymbol{Z} \le 0 \tag{17}$$

where $\boldsymbol{Z} = [\tilde{z} \quad \tilde{U}]^T$ and $\boldsymbol{M} = \begin{bmatrix} \sigma_0 & 1 \\ 0 & 0 \end{bmatrix}$. Since the matrix $\boldsymbol{M}$ is the positive semi-definite, Eq. (17) is negative semi-definite. From the above equation, define $W_2(Z(\tau))$

$$W_2(Z(\tau)) = \sigma_0\tilde{z}^2 + \tilde{z}\tilde{U} \le -\dot{V}_1 \tag{18}$$

That is, $s \to 0$ as $t \to \infty$. and the SMC control system can have the asymptotic stability.

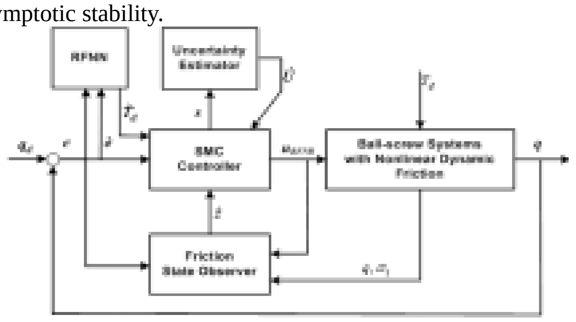


Fig. 1 Schematic diagram of the proposed control system

The estimation of the uncertainty $\hat{T}_d$ is the output of the following RFNN.

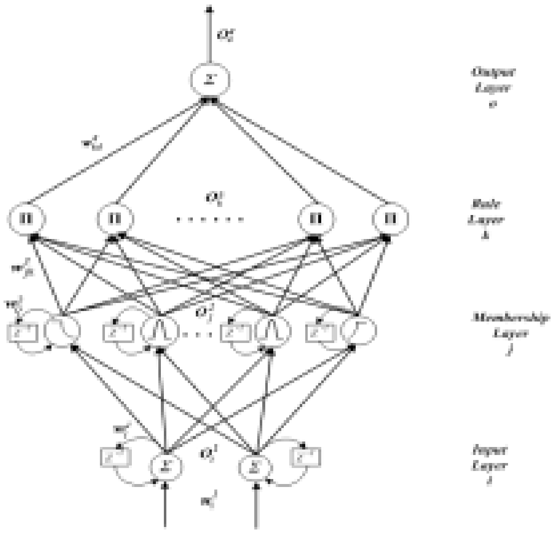


Fig. 2 A schematic diagram of the proposed RFNN

3. Simulation and experiments

In order to prove the effectiveness of the proposed control system, the computer simulation and experiments are executed for the DC motor driven ball-servo system.

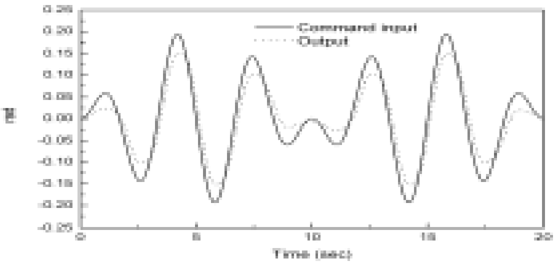
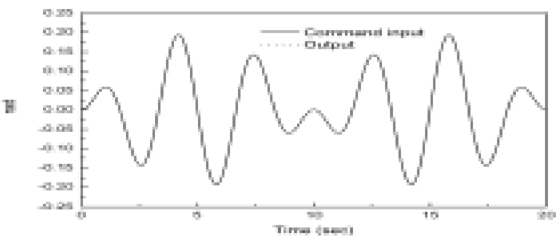
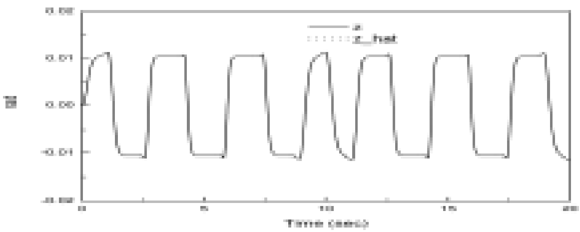


Fig. 3 Simulation results the SMC control system: tracking responses

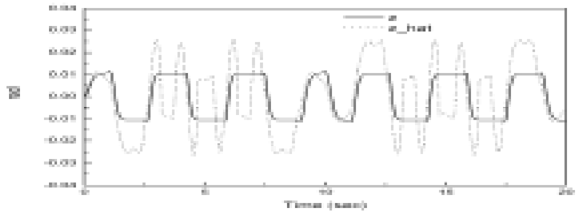


(a) Tracking responses

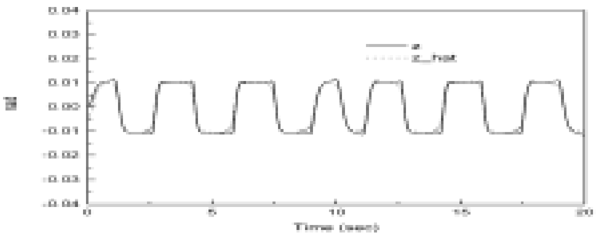


(b) Estimation results: z and $\hat{z}$

Fig. 4 Simulation results of the SMC+OB system: nominal case



(a) SOB control system



(b) SOB+RFNR control system

Fig. 5 Simulation results of z and $\hat{z}$: perturbed case

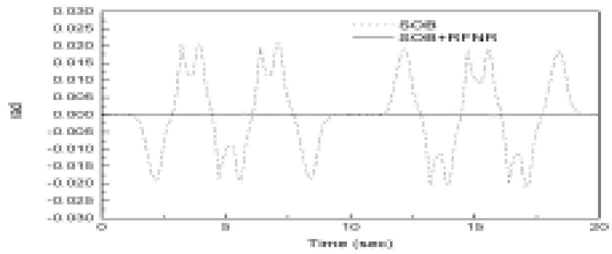


Fig. 6 Simulated results of the SOB and SOB+RFNR system: tracking errors of perturbed case

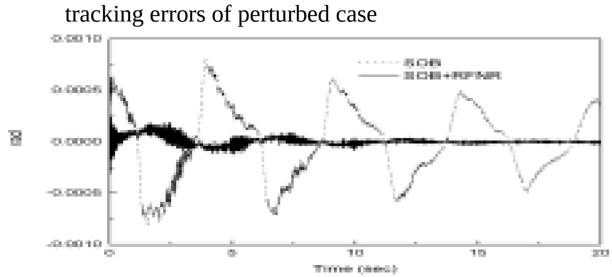


Fig. 7 Experimental results of the SOB and SOB+RFNR control system: tracking errors

4. Conclusion

The SMC and friction state observer with RFNN and estimation error estimator is designed to control the position of the servo system with the dynamic friction. The proposed control scheme maintains the good tracking performance and robustness to the uncertainty of the servo system via the simulation and experiments.

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