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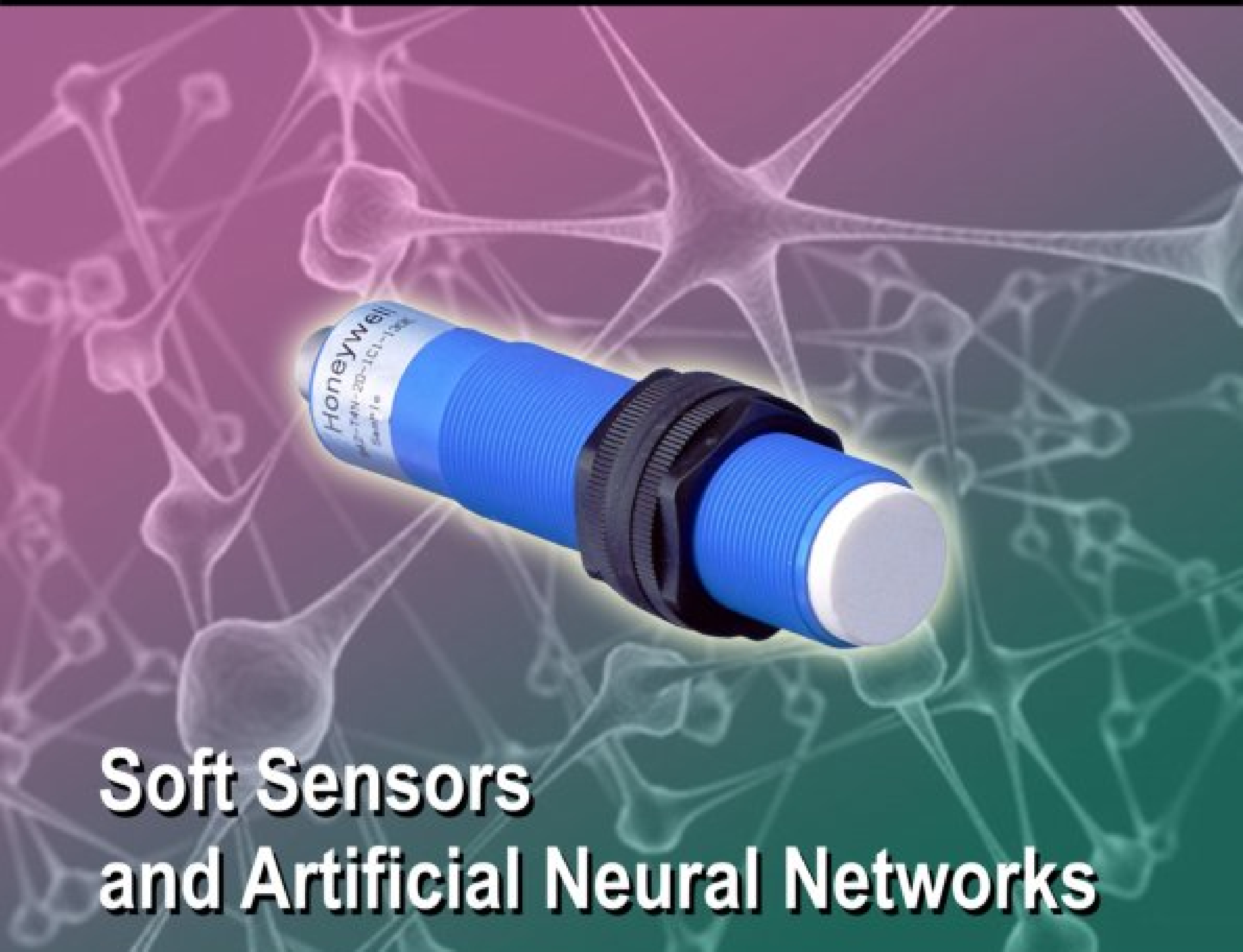

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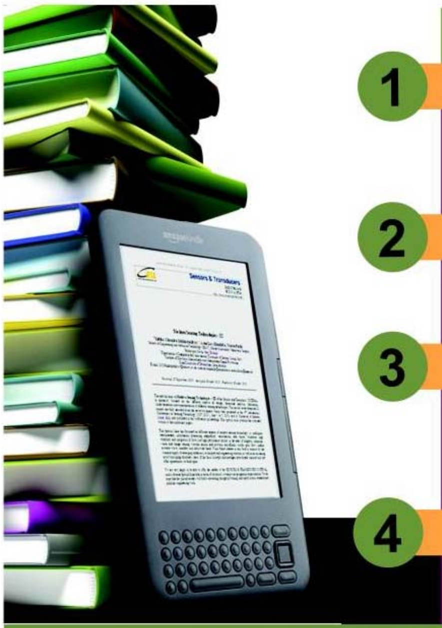

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A Soft Technique for Measuring Friction Force Using Neural Network

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Abstract: There are two approaches to measure a friction force: force sensor, software estimation algorithm. This paper will focus on software approach to measure friction. The proposed approach uses a neural network (NN) to approximate the friction force in a mechanical system. Since the friction force considered is a speed-dependent function, a learning algorithm is adopted to update the NN weights so as to follow unknown friction behaviors. The advantage of the proposed friction estimation method is that it is based on the built NN model, and it does not require the force sensor measurement. Simulation test is given to verify the effectiveness of the proposed approach. *Copyright © 2011 IFSA.*

Keywords: Approximation, Estimation, Friction, Learning, Neural network, Software.

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1. Introduction

Friction occurs whenever two mechanical parts are in contact with each other. No matter which direction one part runs in, friction always pulls it the opposite way. This wastes energy, for a control system in industry must spend extra energy to overcome friction. More importantly, when a controller without consideration of friction, the control performance may be degraded. Therefore, in a practical application, it is quite important to know friction force so that the controller can overcome it. Traditionally, friction force can be measured by using force sensor. The major problems encountered with force sensor are the installation and space requirement, for friction is usually nonlinear and time-varying. To avoid these problems, software approaches based on signal processing technique have been developed.

Various approaches have been proposed for estimating friction using soft method. It has been shown that the use of adequate friction models is the most popular soft approach [1-4]. In [1], a time-delay model is used to describe the hysteresis in friction. In [2], the author uses a couloumb model to represent the friction behaviors. In [3], the authors use viscosity theory to model friction. In [4], the author presents a common model used to describe the Stribeck effect occurred in friction. Other nonlinear friction models can be found in [5, 6].

In this paper, we are intended to use a novel soft method to measure friction. The basic idea of the approach is to use information provided by neural network (NN) to estimate friction force, where the NN is regarded to as an estimator to approximate the friction force. Learning algorithm is proposed in the paper to update the NN weights so as to find a suitable NN function for estimating friction force. To ensure the estimation accuracy, it is also important to generate a sufficient reference signal to excite the control system. Simulation study is given to show how to get a good solution for the proposed soft method.

This paper is organized as follows. A 1-DOF model of mechanical systems is described in Section 2. The NN approximation and learning algorithm are introduced in Section 3. The simulation results are shown in Section 4. Finally, some concluding remarks are given in Section 5.

2. Dynamics of Mechanical Systems

Fig. 1 shows the 1-DOF mechanical system under investigation that is a mass constrained to move in one dimension with friction present between the mass and the supporting surface. The equation for this dynamical system is given by

$$m\ddot{x} = u - F \ , \tag{1}$$

where *m* is the mass of the system, *u* is the external applied force into the block, *x* is the position of the block, and *F* is the frictional force.

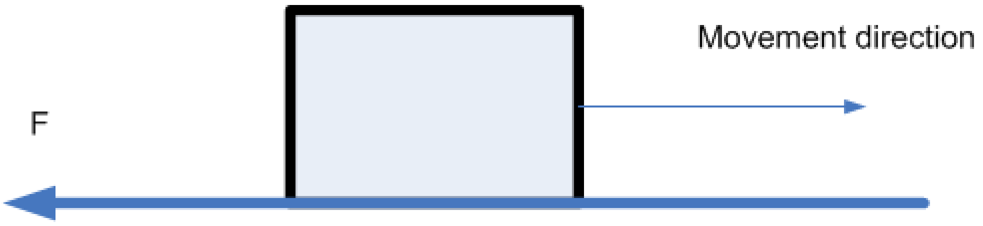

Fig. 1. Friction force and motion object.

The friction behavior can be represented by a mathematical model. The most common used to describe friction takes the following form

$$F = F_c \operatorname{sgn}(\dot{x}) + (F_s - F_c)e^{-|\dot{x}/\dot{x}_s|^{\delta}} + F_v\dot{x} \ , \tag{2}$$

where F_c, F_s, F_v are constants, $\dot{x}_v$ is the Stribeck velocity that defines the region in which such an effect is present, and δ >0. However, friction is a complex physical behavior and traditional models [1-4] are not enough to capture all friction behaviors. It is necessary to develop more complex nonlinear model to accurately describe the friction dynamics.

It is now well known that the friction force is a nonlinear function depending on speed, i.e., $F(\dot{x})$. Thus, how to mimic this nonlinear model is a challenging task in this paper. In light of the above, the present paper has the following task: finding a nonlinear friction model which can approximate dynamical behavior associated to the friction.

3. Friction Estimation Using Neural Network

In this section, we will use the dynamical model (1) to construct a straightforward controller and design a friction estimation algorithm. The objective of the controller is to find a control law *u* to ensure the tracking error as small as possible. This objective will help the friction estimation algorithm achieve a satisfactory performance.

Let tracking error being $e_1 = x_d - x$ and define $e_2 = \dot{x}_d - \dot{x}$ where x_d is the reference signal. Defining the vector $e = [e_1 \quad e_2]^T$, the model (1) can be written as

$$\dot{e} = Ae + B\left(\frac{F-u}{m} + \ddot{x}_d\right) \tag{3}$$

where $\ddot{x}_d$ denotes the second derivative of the reference signal x_d and

$$A = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix},$$

$$B = \begin{pmatrix} 0 \\ 1 \end{pmatrix}.$$

To estimate friction force, we have to design the following controller

$$u = Ke + \hat{F}, \tag{4}$$

where K is the feedback gain and $\hat{F}$ is the estimate of friction force F. The feedback control gain is given by

$$K = -r^{-1}B^T P, \tag{5}$$

where *r* is a constant and *P* is the solution of the Riccati equation

$$A^T P + PA - r^{-1}PBB^T P + Q = 0$$

for a given $Q>0$. Obviously, if $\hat{F} = F$, then the known friction could be well cancelled and the resulting control system is stable. This will achieve a small tracking error. Unfortunately, the friction *F* is unknown *a priori* in practice. As stated in the introduction section, the friction force *F* is a nonlinear function depending on speed and traditional method is difficult to model it. Since neural networks (NNs) have an inherent capability of learning and approximating nonlinear functions, it is attractive to apply them in control systems for modeling purpose. Thus, we have

$$\hat{F} = \hat{W}^T \Phi(\dot{x}), \tag{6}$$

where $\hat{W} = [\hat{w}_1, \hat{w}_2, ..., \hat{w}_N]^T$ is the representative NN weight vector which will be determined by an adaptive law, and $\Phi(\dot{x}) = [\phi_1(\dot{x}), \phi_2(\dot{x}), ..., \phi_N(\dot{x})]^T$ is the NN basis function vector which is fixed in priori. Fig. 2 shows this NN processing structure. The NN weight vector $\hat{W}$ is updated by the following learning law

$$\dot{\hat{W}} = \gamma \Phi(\dot{x}) e^T PB \tag{7}$$

where γ is the learning rate. In summary, as shown in Fig. 3, the NN based friction estimation scheme includes a NN learning system and a feedback controller.

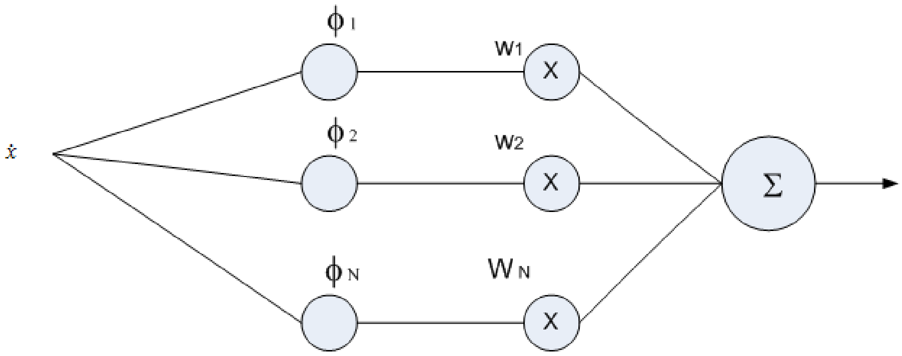

Fig. 2. NN processing structure.

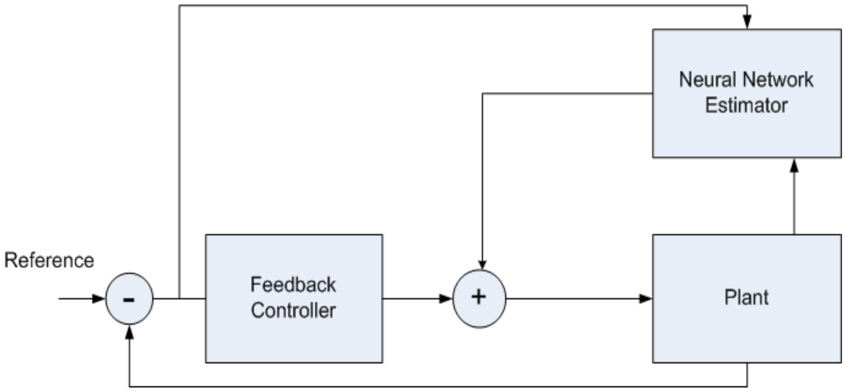

Fig. 3. Block diagram of friction measurement scheme.

Remark. To estimate friction accurately, the NN weight vector $\hat{W}$ should converge (or approach) to its true value. This requires that the reference signal x_d produced should have a multiple frequencies, at least it should contain two frequencies. This is called persistent excitation (PE) conditions [7].

4. Simulation Test

In this section, the preceding technology development is illustrated by a simulation study. For this purpose, we assume that a system with the unknown friction *F* takes the form (2), where

$$F_c = 2, F_s = 4, \dot{x}_s = 0.05, F_v = 2.$$

The mass of the system is $m = 5.59$ kg.

To apply the controller, we have to chose the feedback gain which depends on the equation (5). For a given $Q = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, the feedback gain is obtained and that is $K = (1.41 \quad 2.76)$. However, the control response is poor as shown in Fig. 4. To get a good control performance, we choose other values of Q until $Q = \begin{pmatrix} 300000 & 0 \\ 0 & 1 \end{pmatrix}$ and the feedback gain is $K = (774.59 \quad 55.68)$. This achieves a satisfactory control result as shown in Fig. 5. Notice that the reference signal used in the simulation contains two frequencies. Now we can put a NN into the control system implementing the friction estimate. In our simulation, neural network used is chosen as $\hat{W}^T \Phi(\dot{x}) = \sum_{i=1}^{N} \hat{w}_i \phi_i(\dot{x})$, i.e., N basis function units, where $\hat{w}_i$ is the representative value and $\phi_i(x)$ is the NN basis function given by

$$\phi_i = exp(-\| \dot{x} - a_i \|^2 / b_i^2), i = 1,2,...,N ,$$

where $a_i \in [-5,5]$ and $b_i = 0.5$. The values of $a_i, i = 1,2,...,N$, are evenly spaced in [-5,5]. The learning algorithm (7) is used for tuning the NN weights. Fig. 6 presents the simulation results for the controller, NN estimate and second NN weight (a typical NN weight) proposed by (4), where the NN basis node number is selected as 100, while the learning rate is chosen as 10. It is observed from Fig. 6 that the proposed NN can provide a good approximation of the friction force. It is also seen that a large transient error exists during the initial phase of the friction estimate, due to a lack of knowledge of the plant's friction. Through the NN learning, the neural network can estimate the actual friction force accurately after 20seconds. In this simulation, the selection of the learning rate is important, for it affects the convergence of the NN weights. If the learning rate is chosen as 1, the NN estimate is shown in Fig. 7. Obviously, the estimation takes a long time to approach the actual friction. One way for choosing the learning rate is to observe if the NN weight (see Fig. 6 and Fig. 7) can converge to a stable region quickly. On the other hand, though the learning rate can help improve the NN performance, large value of the learning rate might result in the oscillation of the NN weight.

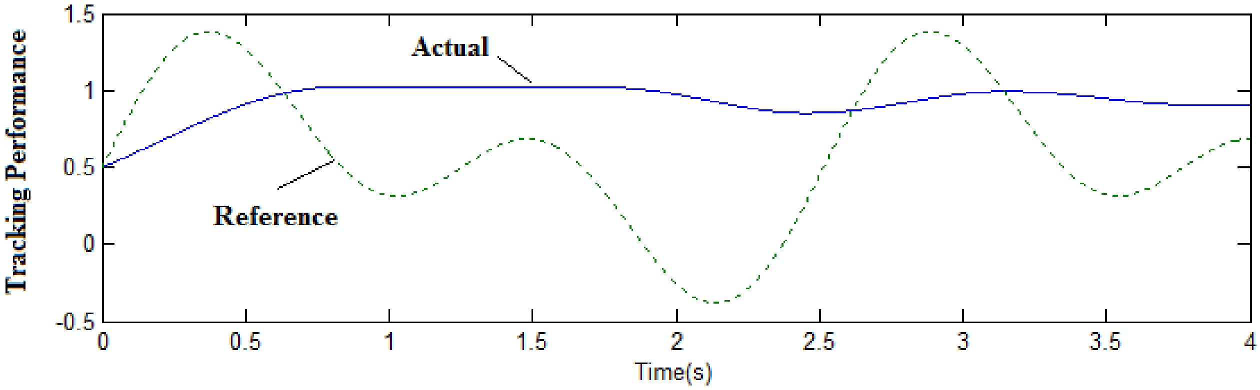

Fig. 4. Control result when $K = (774.59 \quad 55.68)$.

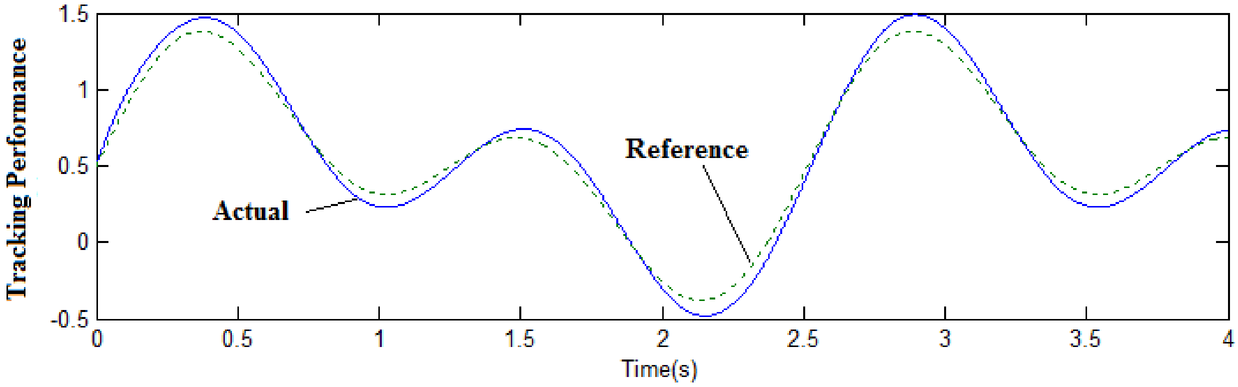

Fig. 5. Control result when $K = (774.59 \quad 55.68)$.

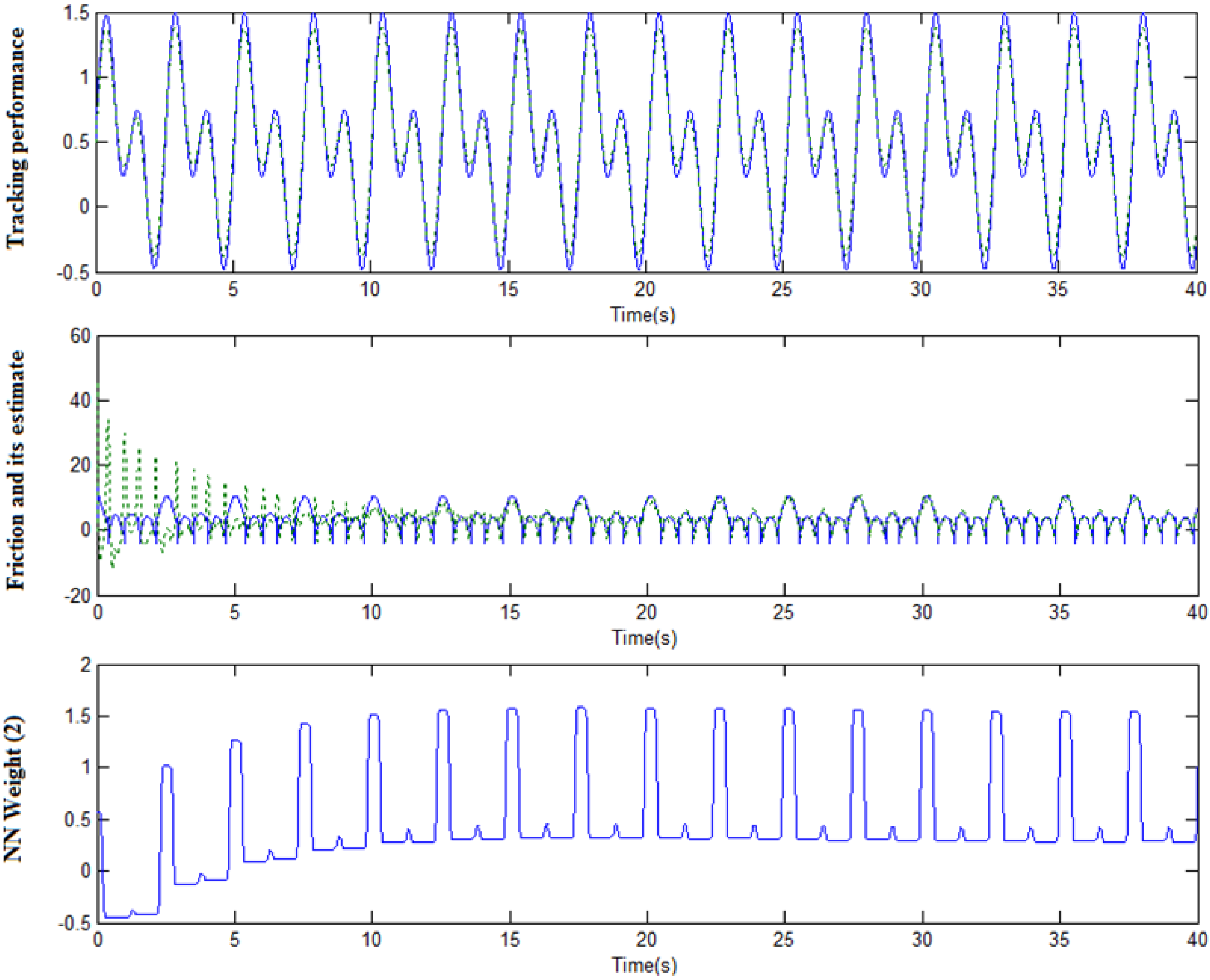

Fig. 6. Tracking performance and friction estimation: dotted line is desired trajectory and solid line is actual response (top); dotted line is actual friction and solid line is NN estimate (middle).

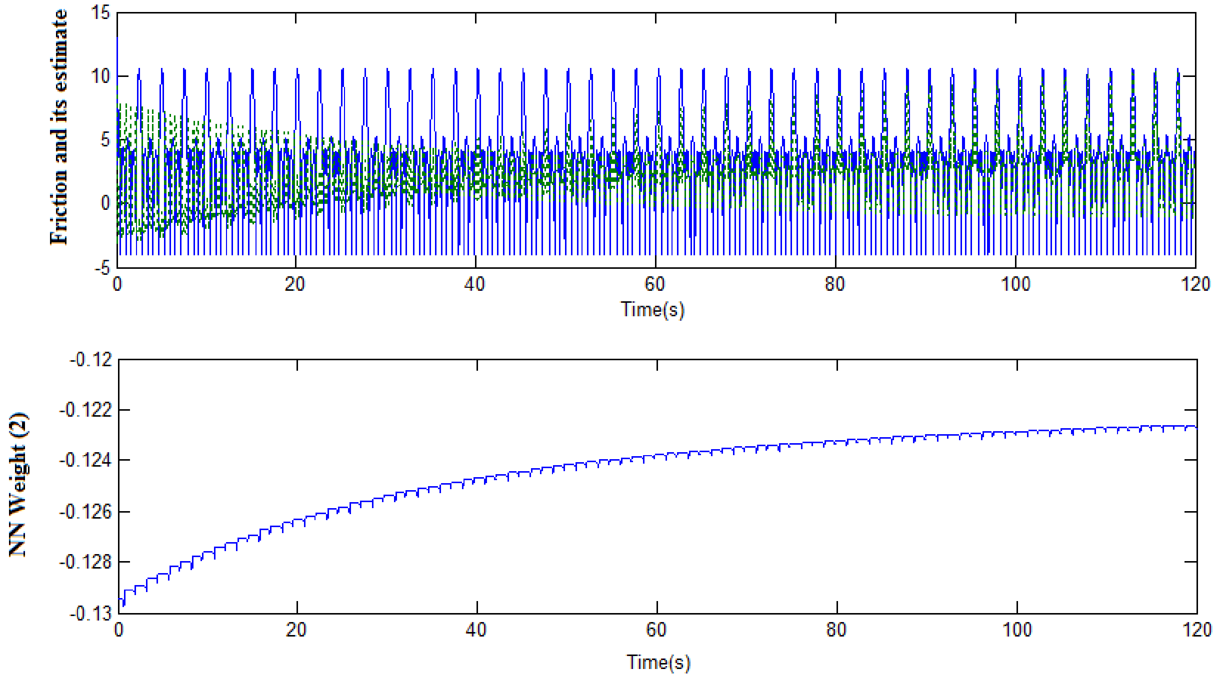

Fig. 7. Friction estimate: dotted line is actual friction and solid line is NN estimate.

5. Conclusions

A new technique for measuring friction has been presented in this work. Instead of working in the traditional hardware approach, we exploited here the soft technique to estimate the friction force on-line. This technique allows us to tune design parameters quickly when the mechanical system changes. The simulation results have shown that the proposed technique is significantly efficient for identifying friction in a mechanical system.

References

[1]. D. P. Hess and A. Soom, Friction at a lubricated line contact operating at oscillating sliding velocities, *Journal of Tribology*, Vol. 112, 1990, pp. 147-152.

[2]. P. E. Dupont, Avoiding stick-slip through PD control, *IEEE Trans. on Automatic Control*, Vol. 39, No. 5, 1994, pp. 1094-1097.

[3]. W. S. Huang, C. W. Liu, P. L. Hsu, S. S. Yeh, Precision control and compensation of servomotors and machine tools via the disturbance observer, *IEEE Trans. on Industrial Electronics*, Vol. 57, No. 1, 2010, pp. 420-429.

[4]. B. Armstrong-Helouvry, Stick-slip and control in low-speed motion, *IEEE Trans. on Automatic Control*, Vol. 38, No. 10, 1993, pp. 1483-1496.

[5]. G. Prisco, D. Q. Larkin and W. C. Nowlin, Control system for reducing internally generated frictional and inertial resistance to manual positioning of a surgical manipulator, *US Patent 7819859*, 2010.

[6] Z. Zhang, T. Xie, G. M. Garstecki, M. Xie,. S. D. Slabbekoorn and A. R. Buendia, Method and apparatus for monitoring load size and load imbalance in a washing machine, *US Patent 7958585*, 2011.

[7]. P. A. Ioannou and J. Sun, Robust Adaptive Control, *Prentice Hall*, Englewood Cliffs, NJ, 1995.

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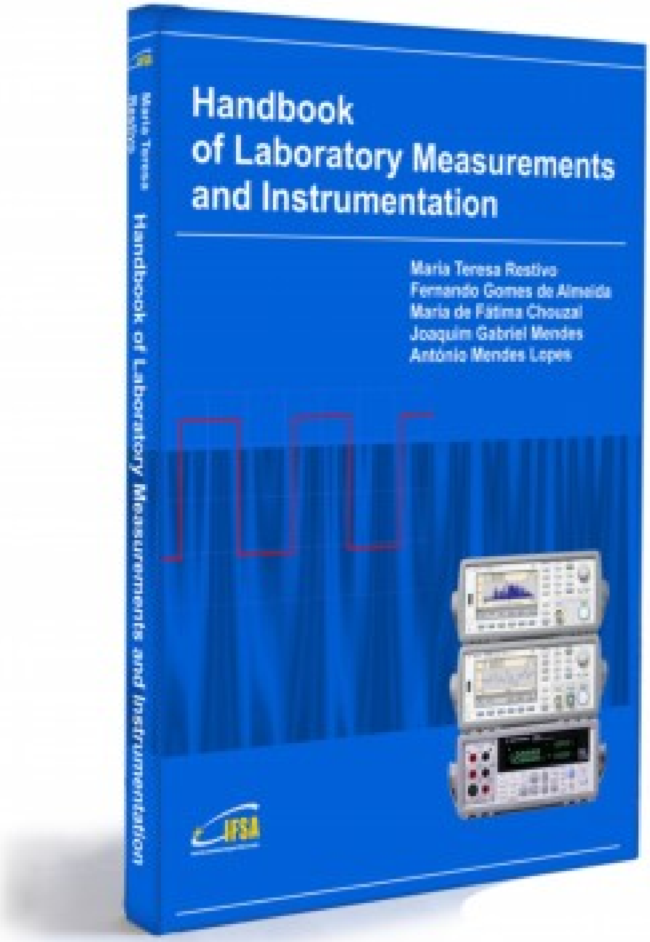

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