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Adaptive Control of Stepping Motors Using Artificial Neural Networks

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Abstract: An Artificial neural network (ANN) based controller is proposed in this paper to simultaneously identify and adaptively control the rotor angular position of the hybrid stepper motors. For implementing the above objective, two distinct feed forward multilayer neural networks, namely neural network identifier (NNI) and neural network controller (NNC), are suggested in this work. The NNI is for accomplishing online identification of the stepper motor drive system. Four inputs to this identifier are estimates of the rotor angular position at previous two instants, output of the identification network. The output signal of NNI is fed to the input of the NNC via tapped delay line. The NNC is for implementing the real time control. The inputs of NNC are the rotor angular position at previous two instants from NNI, The desired angular speed biases are wired to achieve the actual rotor position. The parameters of the NNI are adjusted on the basis of the error between actual motor position the desired angular speed and the control of signal of the previous sampling interval. The parameters of the NNC are adjusted on the error between desired angular position and actual rotor position. It is trained by using EBPA, during training the weights and biases are adjusted for precious positioning operation.

Index Terms—Artificial neural network (ANN), Error back\propagation (EBP), model reference adaptive control, stepper motor.

I. INTRODUCTION

Due to advancements in power electronics and data processing, stepping motors are widely used in robotic manipulators angular and linear measurements, aerospace applications, and machine tools in which they have to perform high-precision speed and positioning operations [1]–[3]. However, mechanical configuration changes such as load torque disturbances and inertia variations, which are common to the above applications, can lead to a loss of synchronism for high stepping rates. Adaptive control methods have been introduced to tackle this problem [4]–[7]. The nonlinear adaptive problem is transformed into a linear adaptive problem by feedback Linearization method at first and then, the adaptive pole assignments and model matching techniques are used to achieve the asymptotic tracking design. The controller achieved good performance by canceling torque-ripple effects. Furthermore, a self-tuning adaptive control technique has been employed to control a stepper motor drive system (SMDS) where the controller is required to adapt the motor operating conditions [7]. It has been found that this controller requires a large amount of floating-point computation, which may lead to increase in the sampling period. Nevertheless, it is still difficult to design and implement a real-time math-model-based optimization control for highly nonlinear, considerably uncertain, and critically coupled SMDS. Artificial NNs offer the advantage of performance improvement through learning using parallel and distributed processing. These networks are implemented by using massive connections among processing units and are attractive for wide applications in system identification and motion controls. Furthermore, intelligent control approaches such as NNs and fuzzy logic systems do not require mathematical models and have the ability to approximate nonlinear systems. The back propagation learning technique is very popular or the multilayer networks. The Error back-propagation (EBP) learning algorithm is proposed for identification and control employing a multilayer perception. The Error-propagation is also used in to describe the application of NNs to the problem of parameter estimation and control for dynamic systems. The NN is functioning as an adaptive controller. Moreover, most of the NN-based adaptive controllers use offline system identification, followed by the control action. This, however, makes the controllers perform inadequately in the presence of quick load changes at the training phase. This paper suggests that it is physically practical to implement an online training of dynamic NNs for identification and control of SMDS. Utilizing two multilayer feed-forward NNs, it makes no such assumptions. The two networks work in tandem to simultaneously achieve system identification and adaptive control. The ability of the controller to achieve the racking process with a high degree of accuracy, even in the presence of external disturbance is also demonstrated.

II. BLOCK DIAGRAM OF THE OVERALL CONTROL STRUCTURE

A. NN-Based control structure

The overall control structure is based on the model reference adaptive control design methodology. It includes two feed forward NNs, the model reference, and the system under control (the stepper drive system). The



overall control structure as shown in fig-1 is adopted to control the rotor speed of the SMDS. The basic idea of this structure is to equate the dynamics of the reference model to that of the system under control. Once the desired trajectory for the speed is specified, the model reference generates the corresponding reference model output,. Two feed-forward NNs are used, one neural network identifier (NNI) for accomplishing online identification of the SMDS, and the other neural network controller (NNC) for implementing the real-time control. Herein, the identification network, namely, 4 : 5 : 1, representing four input layer neurons, five hidden layer neurons, and one output layer neurons, while the controller network, namely, 5 : 5 : 1, representing five input layer neurons, five hidden layer neurons, and one output layer neurons. The number of hidden layers and the number of the neurons in each hidden layer was determined experimentally on a trial and error basis. For this set of experiments only one hidden layer was used in both, the identification and controller networks.

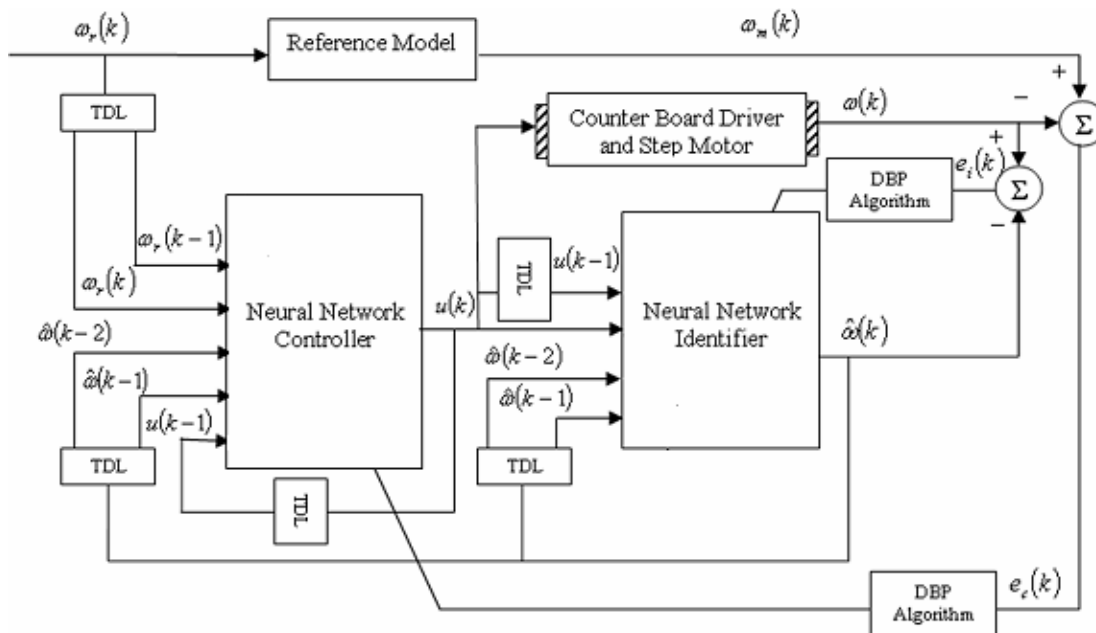


Fig.1. Block Diagram of the Overall Control Structure

B. Description of NNC

The exact form of the control law is unknown, and must be estimated by the NNC. The NNC is a single NN with five inputs and one output. The five inputs to the NNC are, in succession, the estimate of the previous rotor angular speed, the estimate of the rotor angular speed at the previous two instants, the input, the previous instant to the reference model, and the control signal at the previous sampling interval. The NNC is trained online to capture the implicit and unknown mapping that would force the rotor angular speed to follow the desired reference trajectory. The parameters of the NNC are adjusted on the error between the reference model output, and the actual output of the system under control for a given class of input signals. If the system under control deviates from the reference model, the NNC maneuvers the system back to track the reference model. In this paper, the following first-order model is used: where is the bounded input to the reference model and the constant coefficients were chosen to guarantee bounded input-bounded output stability. Consequently, the steady-state reference track is dictated by the amplitude and functional form of the input to the reference model. Note that the control structure is not restrictive in terms of the shape of the reference track. Any restriction, however, is imposed by the hardware limitations of the system under control. To reduce any unnecessary stress, the tracks should conform to the dynamic of the system. Once the design of the topologies of the NNI and NNC are completed, the next step is to determine the weights and biases of both networks through training to achieve the specific target with given inputs.

C. Description of NNI

The NNI is a single NN with four inputs and one output. The four inputs to the NNI are, in succession, estimate of the previous rotor angular speed, the estimate of the rotor angular speed at the previous two instants, the actual control effort and the delayed control effort. The NNI is used to approximate, as a function of its four



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input arguments. In this case, the function approximation equals the estimate of the rotor angular speed. The parameters of the NNI are adjusted on the error between, the actual motor speed and the output of the identification network. The key principle involved during training is to vary the weights and biases of the NNI so that the actual motor speed approaches its estimates as tend to infinity.

D. Learning algorithm

The Error back propagation algorithm is used to train both the NNI and NNC; other existing online learning algorithms for tuning the weights of the NNs can also be adopted for tuning both networks. The algorithm is straightforward and based on the principle of the minimization of a cost function of the error between the desired output and the actual output of each network. The minimization is achieved by varying the adjustable parameters of the NNI and NNC in the negative direction of the gradient of the cost function. The most important step in the employed algorithm is the computation of the partial derivatives of each of the outputs of the network with respect to each of its adjustable parameters.

III. MODELING OF STEPPER MOTOR

The equation of motion of the rotor is

$$J \frac{d^2\theta}{dt^2} + D \frac{d\theta}{dt} + pn\Phi_m i_a \sin p\theta + pn\Phi_m i_b \sin p(\theta - \lambda) = 0$$

Where

$n\Phi$ - flux linkage

D - Viscous damping coefficient in Ns/m

J - Moment of inertia in Kg/m²

Linear differential equation is

$$J \frac{d^2(\delta\theta)}{dt^2} + D \frac{d(\delta\theta)}{dt} + 2p^2 n\Phi_m I_o (\cos p\lambda) \frac{(\delta\theta)}{2} + pn\Phi_m (\sin p\lambda) (\delta_{iA} - \delta_{iA}) = 0$$

Putting $\lambda=0$

$$J \frac{d^2(\delta\theta)}{dt^2} + D \frac{d(\delta\theta)}{dt} + 2p^2 n\Phi_m I_o \delta\theta + \delta\theta = \theta_0 - \theta_i$$

$$J \frac{d^2\theta_0(t)}{dt^2} + D \frac{d\theta_0(t)}{dt} + 2p^2 n\Phi_m I_o \theta_0(t) = 2p^2 n\Phi_m I_o \theta_i$$

Laplace transform of this equation with initial conditions

$$\theta_0 = 0, \quad \frac{d\theta_0}{dt} = 0 \text{ at } t = 0 \text{ is}$$

$$s^2 J + sD + 2p^2 n\Phi_m I_o \theta_o(s) = 2p^2 n\Phi_m I_o \theta_i$$

$$G(s) = \frac{\theta_o(s)}{\theta_i(s)}$$

$$= \frac{2p^2 n\Phi_m I_o}{s^2 J + sD + 2p^2 n\Phi_m I_o}$$

$$G(s) = \frac{\omega_{np}^2}{s^2 + s D/J + \omega_{np}^2}$$

Where

$\theta_o(s)$ - Actual position

$\theta_i(s)$ - Demand position

ω_{np} - Angular speed (rad/s)

IV. SIMULATION RESULTS

The entire system was simulated by applying the stepper motor parameters in the above equation. The simulation result shows the proposed ANN controller reduces the settling time. In the case of PI and PID



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controllers the settling time is .26 ms and .1ms respectively. But the proposed controller output is .045 ms.

A. CONVENTIONAL CONTROLLERS

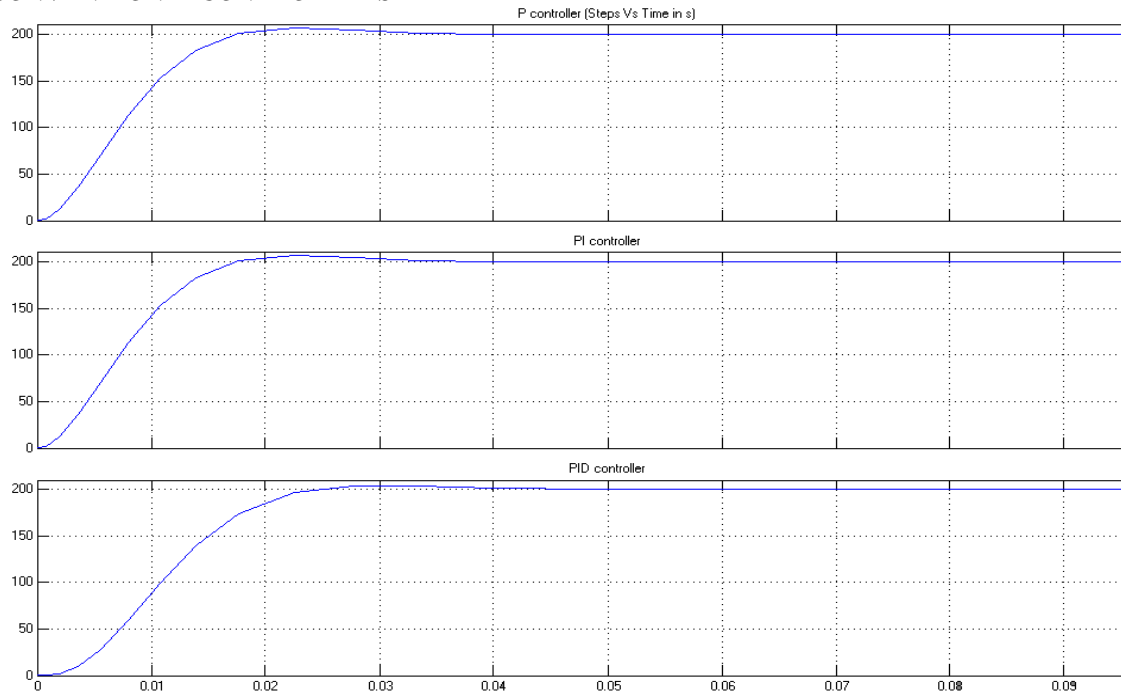


Fig.2 Characteristic of Conventional Controller

B. PROPOSED CONTROLLER

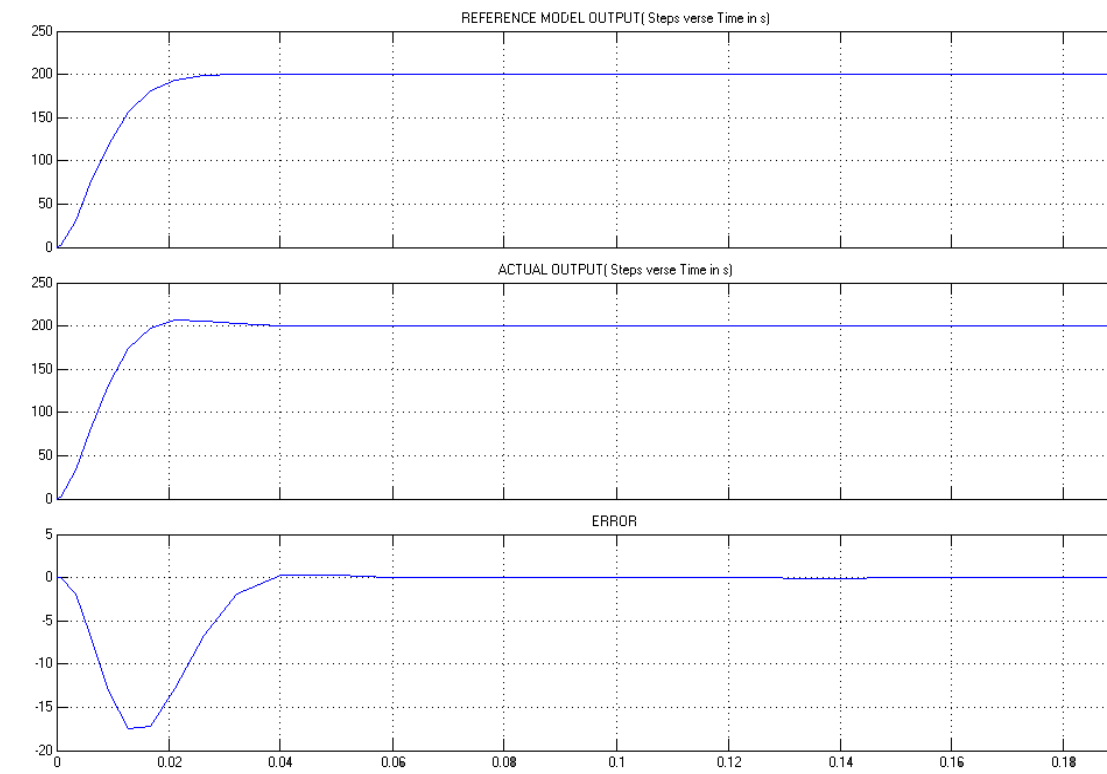


Fig.3 Characteristic of Proposed Controller



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IV. STEPPER MOTOR PARAMETERS

Voltage	= 12 V
Current	= 1.4 A
Resistance	= 3 Ω
Moment of inertia	= 0.0162 Kg/m ²
Damping coefficient	= 0.54 Ns/m
Step angle	= 1.8 Degree

V. CONCLUSION

This paper has presented a successful simulation of two NN structures that possesses the capabilities of simultaneous online identification and control to cope with a high-performance SMDS. The two networks are trained online utilizing the EBP learning algorithm. The SMDS under control was identified by the NNI to provide its sensitivity information for the online training of NNC. The proposed structure features wide speed operating range, from zero up to the rated speed. A number of reference tracks were used in the experimental implementation, and practically accurate tracking results were obtained. Experimental results have shown that the proposed control structure tracks the trajectories successfully, even under external disturbances and noisy environment. A comparison with conventional controllers has shown the advantage of the proposed scheme.

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