Remarks on tracking method of neural network weight change for learning type neural network feedforward feedback controller

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Abstract: Although there are many neural network controllers are proposed, we should still tune several parameters of neural networks in order to obtain well neural network learning performance in practical applications. Our tracking method can be provided as a new aspect for this neural network parameter tuning. It has been applied to an adaptive & a learning type neural network direct controllers and an adaptive type neural network feedforward feedback controller. This paper applied it to a learning type neural network feedforward feedback controller. Simulation results confirmed its usefulness and discussed a transformation of the track on 2D plane to one dimensional value.

Keywords: Neural network, Controller, Learning, Adaptive

I. INTRODUCTION

Many studies have been undertaken in order to apply both the flexibility and the learning capability of neural networks to control systems. Although there are many neural network controllers are proposed, we should still tune several parameters of neural networks in order to obtain well neural network learning performance in practical applications. Learning rules of neural networks are usually designed so as to minimize the squared error between a plant output (or neural network output) and a desired output (teaching signal). This squared error is usually observed in order to tune parameters of neural networks and to examine which neural networks are suitable. However, the essence of neural network learning rules is nothing but the change of the neural network weights. It is not always reflected in the squared error. This is because the object plant has dynamics and the squared error is affected by this plant dynamics. The reason of the use of the squared error is that a usual neural network has huge number of its weights and it is difficult to observe whole neural network weight change in neural network learning progresses. On the other hand, the squared error is a scalar value and it is easily dealt with.

Thus, we proposed a tracking method of neural network weight change as a better examination method for neural network leaning performance.[1] This tracking method derives a weight vector form whole neural network weights. We can calculate an angle between this weight vector and a standard vector. The neural network weight change can be directly drawn on 2D plane by use of the norm of the weight vector and the above angle. Drawn trajectories on 2D plane are not affected by the plant dynamics in comparison with the observation of the squared error. This is because the plant output is not used. Our tracking method is easier to dealt with than observation of whole neural network weight change. We have applied this tracking method to both a learning type and an adaptive type neural network direct controllers and confirmed its usefulness.[1][2] Next, it has been applied to an adaptive type feedforward feedback neural network controller which uses the sum of the neural network output and the feedback loop output as a plant input.[3][4] The feedfoward feedback controller has more complex structure in comparison with the direct controller. This is because the direct controller uses only neural network output as a plant input. However, we can expect more robustness because the feedback loop can compress that the control system becomes to be unstable in earlier learning stage.

This paper applied our tracking method of the neural network weight change to a learning type neural network feedforward feedback controller. The simulation results confirmed its usefulness which is similar to those of both the learning type direct controller and the adaptive type feedforward feedback controller. We noticed through the simulation that it was hard for untrained users to observe the neural network weight performance on 2D plane in some cases. To overcome this problem, this paper also discussed a transformation of the track on 2D plane to one dimensional value.

II. TRACKING METHOD OF NEURAL NETWORK WEIGHT CHANGE

This section explains the tracking method of the neural network weight change briefly. This tracking method is applied to the learning type neural network feedforward feedback controller for the SISO plant. In this paper, an output layer of the neural network has one neuron, the weights between the output layer and a hidden layer can be expressed as a vector ω and the weights between the hidden layer and an input layer can be expressed as a matrix W. To simplify, the neuron number of the input layer is equal to that of the hidden layer. That is, the weight matrix W is the square matrix. The tracking method uses the following steps.

(Tracking method of neural network weight change)
(1) We can derive one weight vector Γ from the neural network weight vector ω and weight matrix W as follows:

$$\Gamma^T = [\omega_1 \cdots \omega_n\ W_{11} \cdots W_{1n} W_{21} \cdots W_{2n} \cdots W_{n1} \cdots W_{nn}] \quad (1)$$

Where n is the neuron number both the input layer and the hidden layer.

(2)We must define a standard vector Γ_0. Any vector, which has same order as that of the weight vector Γ, can be selected as this standard vector, for example, the weight vectors derived from the initial neural network weights, the final neural network weights and so on.

(3) We can calculate an inner product of the weight vector Γ and the standard vector Γ_0 because these vectors have same order. We can also calculate an angle between the weight vector Γ and the standard vector Γ_0 as follows:

$$X = |\Gamma| \cos\theta, \quad Y = |\Gamma| \sin\theta \quad (2)$$

$$\theta = \cos^{-1}\left(\frac{\langle \Gamma_0 \cdot \Gamma \rangle}{|\Gamma_0| \cdot |\Gamma|}\right) \quad (3)$$

Where $\langle \Gamma_0 \cdot \Gamma \rangle$ is the inner product between the vector Γ_0 and the vector Γ, and $|\Gamma|$ is the norm of the vector Γ.

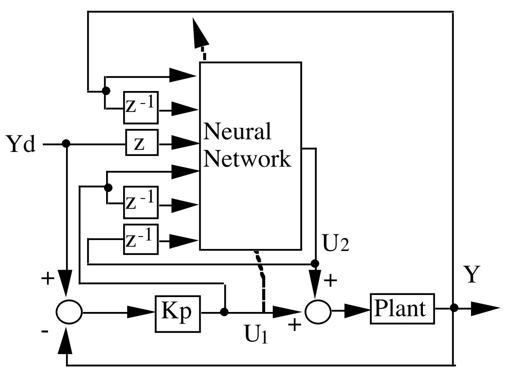

Fig.1 Block diagram of neural network feedforward feedback controller for second order discrete time plant.

(4) We can draw a new weight performance on the 2D plane by the use of X and Y in equations (2) and (3).

III. SIMULATION

This paper applies the tracking method of the neural network weight change to the learning type neural network feedforward feedback controller. The simulated plant is follows:

$$Y(k) = -a_1 Y(k-1) - a_2 Y(k-2) + U(k-1) + bU(k-2) - a_3 Y(k-3) + C_{non} Y^2(k-1) \quad (4)$$

Where Y(k) is the plant output, U(k) is the plant input, k is the sampling number, a_1, a_2 & b are the plant parameters, a_3 is the parasite term and C_{non} is the nonlinear term. For this simulation, a_1=-1.3, a_2=0.3, b=0.7, a_3=-0.03 and C_{non}=0.2 are selected. The rectangular wave is also selected as the desired value Yd. The output error ε and the cost function J are defined as follows:

$$\varepsilon(k) = Yd(k) - Y(k)$$

$$J(p) = \frac{1}{2} \sum_{k=1}^{\rho} \varepsilon^2(k) \quad (5)$$

Where p is the trial number and ρ is the sampling number within one trial period.

For this simulated plant, the neuron number n in both the input and hidden layers is 6. The neural network input vector I is defined as the following equation.

$$I^T(k) = [Y_d(k+1)\ Y(k)\ Y(k-1)\ U_2(k-1)\ U_1(k)\ U_1(k-1)] \quad (6)$$

Where U1(k) and U2(k) are the feedback loop output and the neural network output respectively. We select the following sigmoid function f(x) as the input output relation of the hidden layer neuron.

$$f(x) = \frac{X_g\{1-\exp(-4x/X_g)\}}{2\{1+\exp(-4x/X_g)\}} \quad (7)$$

Where Xg is the parameter which defines the sigmoid function shape. The neural network output U2(k) is composed as follows:

$$U_2(k) = \omega^T(p) f\{W(p) I(k)\} \quad (8)$$

When we use the P control (Proportional control), the feedback loop output U1(k) is composed using the feedback gain Kp as shown in the following equation.

$$U_1(k) = Kp\{Yd(k) - Y(k)\} \quad (9)$$

The plant input U(k) of the feedforward feedback neural network controller is the sum of the neural network output and the feedback loop output as follows:

$$U(k) = U_1(k) + U_2(k) \qquad (10)$$

The block diagram of the learning type neural network feedforward feedback controller is shown in Fig.1. The learning rule of this neural network controller is designed so as to minimize the feedback loop output. When we apply the δ rule to this learning rule, it is expressed as follows:

$$W_{ij}(p+1) = W_{ij}(p) + \sum_{k=1}^{\rho} [\eta U_1(k)\omega_i(p) I_j(k-1) \times f'\{\sum_{j=1}^{n} W_{ij}(p) I_j(k-1)\}] \qquad (11)$$

$$\omega_i(p+1) = \omega_i(p) + \sum_{k=1}^{\rho} [\eta U_1(k) f\{\sum_{j=1}^{n} W_{ij}(p) I_j(k-1)\}] \qquad (12)$$

Where η is the parameter to determine the neural network learning speed. We select the weight vector derived from the initial neural network weights as the standard vector Γ_0 of the equations (2) and (3)

Fig.1 shows the plant output (p=1) before learning. As shown in this figure, there is large output error between the plant output and the desired value. Figs.2 and 3 show the plant output (p=200) after learning and the cost function respectively. As shown in these figures, there is the error remained in the first cycle of the desired value, but it becomes to be small in other parts and the cost function smoothly decreases. This means that the neural network learning performs well.

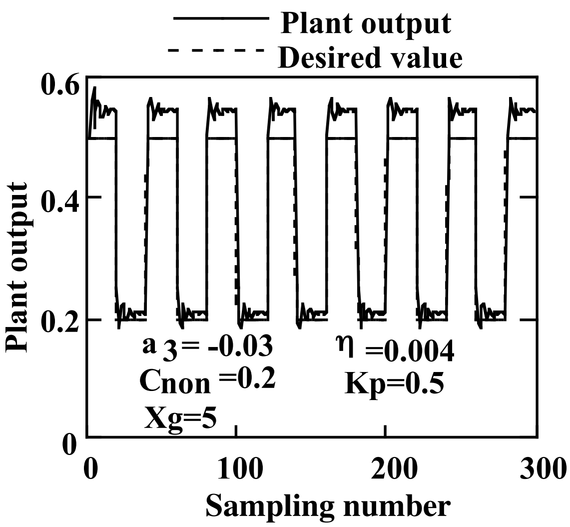

Fig.2 Plant output (p=1) before learning.

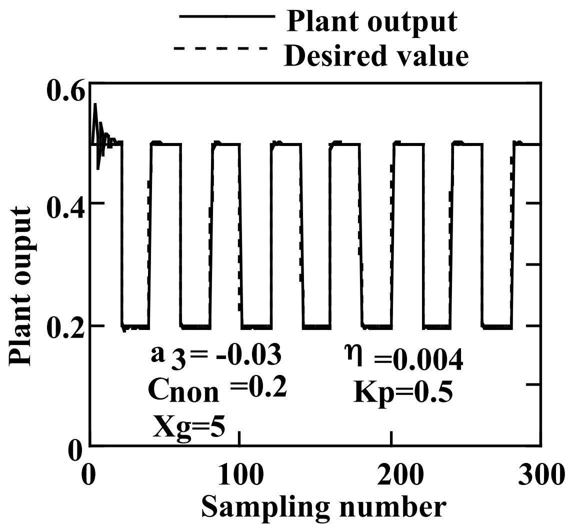

Fig.3 Plant output (p=200) after learning.

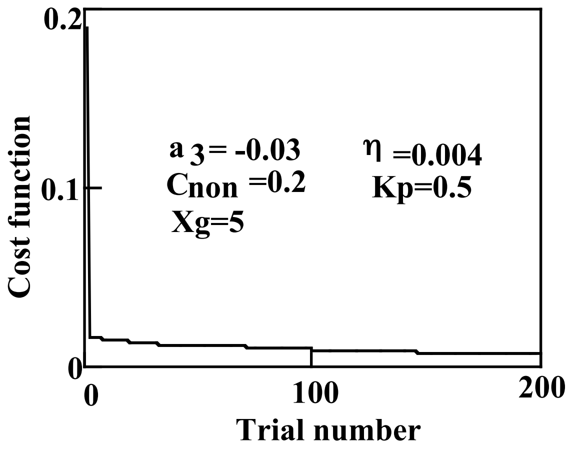

Fig.4 Cost funtion.

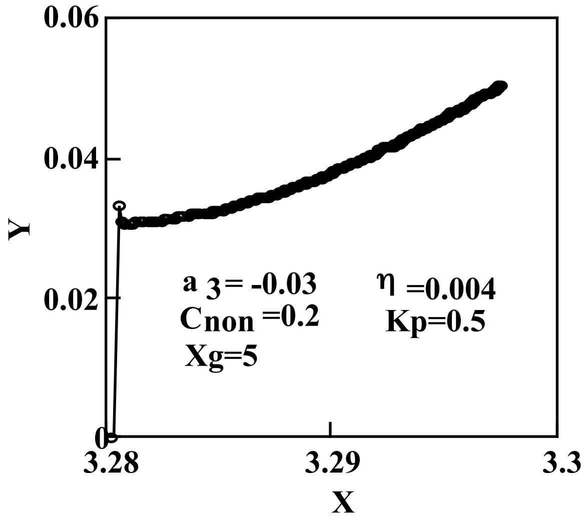

Fig.5 Track of neural network weight change.

Fig.5 shows the track of the neural network weight change. As shown in this figure, our tracking method is also useful for a learning type neural network feedforward feedback controller.

Fig.6 shows the other example of the track of the neural network weight change. As shown here, it may not be easy for untrained users to distinguish whether the neural network learning performance in fig.6 is well or not. To overcome this problem, one choice is a transformation of the track on 2D plane to one dimensional value. Following equation is one example.

$$V_W(p) = \sqrt{(X(p+1) - X(p))^2 + (Y(p+1) - Y(p))^2} \tag{13}$$

Fig.7 shows the one dimensional value Vw in the initial learning stage. As shown in fig.7, the Vw smoothly decreases and this transformation is easily dealt with. This discussion also has another advantage. Fig.8 shows the cost function in initial leaning stage. As shown here, there is little vibration and this may be caused by the plant dynamics. Other possibility is to be caused by the vibration of the neural network weight vector element or the weight matrix element observed only by 2D plane. Advanced study for this problem is our future work.

IV. CONCLUSION

This paper applied the tracking method of the neural network weight change to the learning type neural network feedforward feedback controller. The simulation results confirmed its usefulness. We also discussed a transformation of the track on 2D plane to one dimensional value in order to realize an easier expression of the neural network weight change for untrained users.

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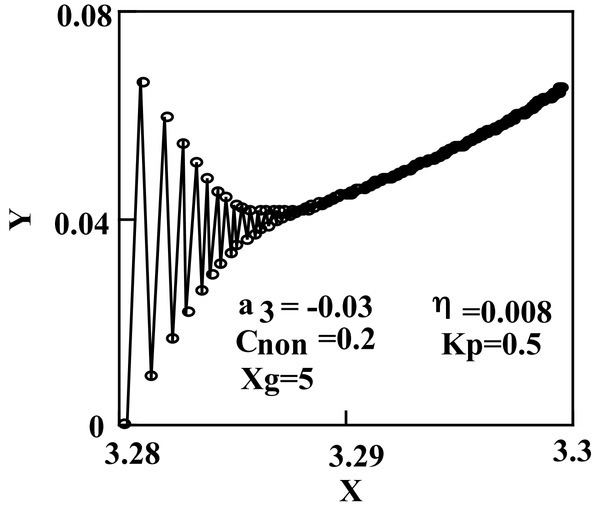

Fig.6 Track of neural network weight change.

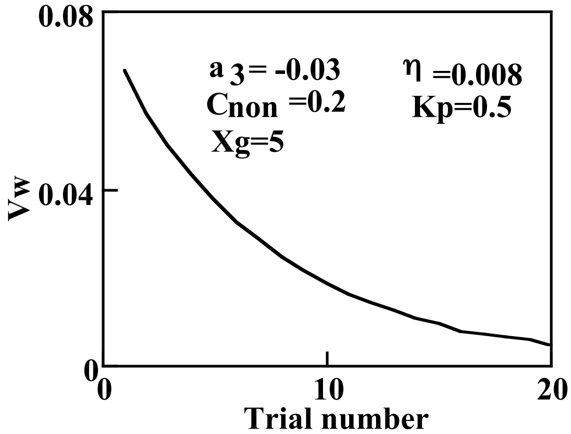

Fig.7 Vw.in initial learning stage.

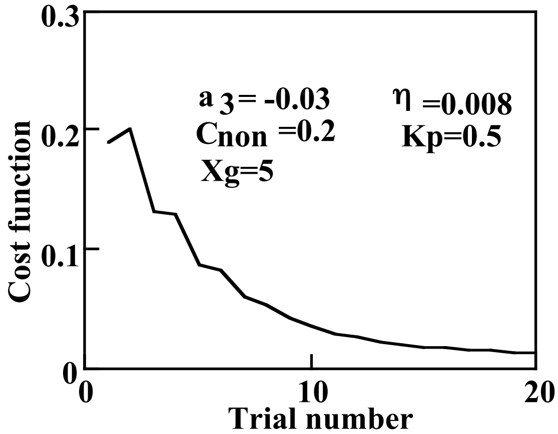

Fig.8 Cost function in initial learning stage.