불확실성을 갖는 비선형 시스템의 자기 회귀 웨이블릿 신경망 기반 터미널 슬라이딩 모드 제어

Self-Recurrent Wavelet Neural Network Based Terminal Sliding Mode Control of Nonlinear Systems with Uncertainties

이신호*, 최윤호**, 박진배***
Sin Ho Lee, Yoon Ho Choi, Jin Bae Park

Abstract - In this paper, we design a terminal sliding mode controller based on neural network for nonlinear systems with uncertainties. Terminal sliding mode control (TSMC) method can drive the tracking errors to zero within finite time. Also, TSMC has the advantages such as improved performance, robustness, reliability and precision by contrast with classical sliding mode control. For the control of nonlinear system with uncertainties, we employ the self-recurrent wavelet neural network(SRWNN) which is used for the prediction of uncertainties. The weights of SRWNN are trained by adaptive laws based on Lyapunov stability theorem. Finally, we carry out simulations to illustrate the effectiveness of the proposed control.

Key Words : Terminal sliding mode control, Nonlinear system, Self-recurrent wavelet neural network, Lyapunov stability theorem

1. Introduction

Many nonlinear systems are used in real applicable technologies. Those nonlinear systems have many actual uncertainties such as the structured and parametric uncertainties. Model imprecision may come from actual uncertainties about the plant or from the purposeful choice of a simplified representation of the system's dynamics[1]. Generally, sliding mode control(SMC) method for those nonlinear systems with uncertainties such as biped robot and spacecraft because of stability[1],[2].

Recently, a new control method called terminal sliding mode control(TSMC) has been developed[3]. While classical SMC has a linear sliding surface, TSMC has a nonlinear sliding surface. The system tracking error is driven to zero within finite time while those reached to terminal sliding surface. Also, TSMC has the following advantages in comparison with classical SMC[3]. First, TSMC has the improved performance that results from the elimination of chattering. Second, TSMC has the improved robustness. This results from the dependence of terminal slider stability upon the rate of change of uncertainties. Third, TSMC has the improved reliability which is yielded by the elimination of interpolation regions. Finally, TSMC has the more improved precision than classical SMC.

However, the stability is not guaranteed for nonlinear systems with uncertainties. So, we use the neural network to solve that problem. Especially, self-recurrent wavelet neural network(SRWNN) is proposed among many famous neural networks in this paper. As matter of fact, many neural networks, such as multi-layer perception(MLP)[4], radial based function network(RBFN)[5], etc are used. Also, wavelet neural network(WNN) is used as the good tool for the estimation of many nonlinear system with uncertainties[6]. However, even though the WNN has fast convergence ability, it cannot confront the unexpected change of system because it dose not have memories. So, we employ the SRWNN which has the memories to overcome this disadvantage of WNN[7].

In this paper, we proposed the control method of nonlinear system with uncertainties, using the SRWNN based TSMC for the stability of systems. All weights of the SRWNN are trained by adaptive laws based on Lyapunov stability theorem, which is used to guarantee the stability of control systems. Finally, we carry out computer simulations for a simple nonlinear system with uncertainties in order to verify the effectiveness of SRWNN based TSMC.

2. Terminal Sliding Mode Control

TSMC has a nonlinear sliding surface in order to obtain the finite time convergence of the system tracking error. So, we defined the terminal sliding surface as follows:

저자 소개
* 이신호: 延世大學校 電氣·電子工學科 碩士課程
** 최윤호: 京畿大學校 電子工學部 敎授·工博
*** 박진배: 延世大學校 電氣·電子工學科 敎授·工博

$$s = \dot{e} + \alpha e^{\gamma} \tag{1}$$

where $\alpha > 0$ and $0 < \gamma < 1$.

The terminal sliding surface can be described as follows:

$$s = \dot{e} + \alpha e^{\gamma} = 0 \tag{2}$$

Eq. (2) can be expressed into the following form:

$$\dot{e} = -\alpha e^{\gamma} \tag{3}$$

In the TSMC, the system tracking error is determined by Eq. (3). Also, the system is infinitely stable in TSM because Eq. (3) defines the exponentially stability. However, if we select proper γ, we can get a final time. This fact shows that the system is finitely stable. The convergence time for a solution of Eq. (3) is given by

$$\frac{de}{dt} = -\alpha e^{\gamma} \Rightarrow dt = -\frac{de}{\alpha e^{\gamma}}$$

$$t = -\int_{e(0)}^{0} \frac{de}{\alpha e^{\gamma}} = \frac{|e(0)^{1-\gamma}|}{\alpha(1-\gamma)} \tag{4}$$

where, $e(0)$ is the initial value of e at t=0.

From Eq. (4), we know that the system tracking error converges to zero within finite time.

3. Self Recurrent Wavelet Neural Network

The SRWNN structure is shown in Fig. 1. The basic structure of SRWNN is composed of N_i inputs, one output, and $N_i \times N_w$ mother wavelets. The SRWNN is consists of four layers as follows[7]:

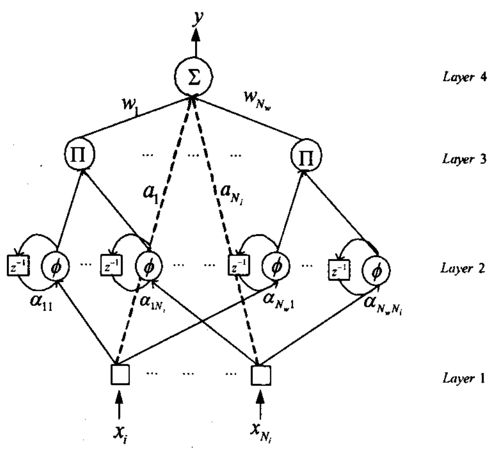

Fig. 1 The SRWNN structure.

The layer 1 is an input layer. This layer accepts the input variables and transmits the accepted inputs to the next later directly.

The layer 2 is mother wavelet layer. Each node of this layer has a mother wavelet and a self-feedback loop. In this paper, we select the first derivative of Gaussian function of a mother wavelet function.

The layer 3 is product layer. The nodes in this layer are given by the product of the mother wavelets.

The layer 4 is output layer. The node output is a linear combination of consequences obtained from the output of layer 3. In addition, the output node accepts directly input values form the input layer. Therefore, the SRWNN output is composed by self-recurrent wavelets and parameters.

4. Simulation Example

Consider the five-link biped robot as follows[2]:

$$H(q)\ddot{q} + B(q,\dot{q}) + G(q) + \Xi(q,\dot{q},\tau) = \tau_q \tag{5}$$

where, $\Xi(q,\dot{q},\tau)$ is the uncertainty of the robot system.

The above equation can be rewritten as follows:

$$\begin{aligned} \ddot{q} &= H^{-1}(q)(\tau_q - B(q,\dot{q}) - G(q) + \Xi(q,\dot{q},\tau)) \\ &= H^{-1}(q)(\tau_q - B(q,\dot{q}) - G(q)) + \Upsilon(q,\dot{q},\tau) \end{aligned} \tag{6}$$

Here, the uncertainty term $\Upsilon(q,\dot{q},\tau)$ cannot be computed directly, so we use SRWNN[7]. Also, we use the classical sliding surface and terminal sliding surface, respectively, for the control of system.

First, we use the classical sliding surface as follows:

$$s = \dot{e} + \alpha e \tag{7}$$

Second, we use the terminal sliding surface as Eq. (1). Also, the parameter of the robot model is used in [5]. We simulate SMC with 100% parametric uncertainty of which 100% each of parameter value is added on the mass and the moment of inertia. We choose the control gain λ. Also, we simulate within final time 2 sec, and the sampling time is chosen as 0.002 sec. In this paper, we use the SRWNN to solve uncertainty problem. At this time, we give the positive tuning gains, λ_c and λ_e to guarantee the stability of our control system,.

Originally, SMC technique is good controller. However, SMC has a disadvantage such as chattering. So, we use TSMC technique to solve this problem. Also, TSMC has more efficient tracking performance than SMC. The results of mean square error(MSE) for SMC and TSMC are shown in Figs. 2 and Fig 3, respectively.

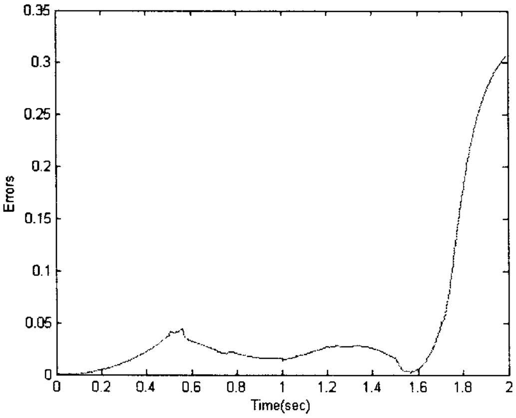

Fig. 2 Mean square error for SMC.

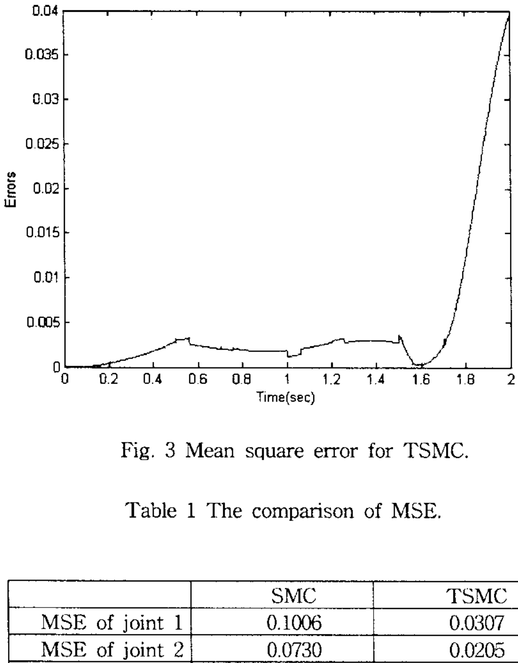

Fig. 3 Mean square error for TSMC.

Table 1 The comparison of MSE.

	SMC	TSMC
MSE of joint 1	0.1006	0.0307
MSE of joint 2	0.0730	0.0205
MSE of joint 3	0.0720	0.0218
MSE of joint 4	0.0776	0.0245

Though SMC is efficient control technique, its performance is degraded for the system with uncertainties. In this paper, this uncertainty problem is solved by SRWNN.

We verify the advantage of TSMC from the simulation results, and these results are shown in Figs. 2 and 3, and Table 1. Figures 1 and 2 show the MSE for SMC and TSMC, respectively. From these figures, we can verify the difference for two cases. Table 1 compaeres simulation results of SMC and TSMC, where the MSE of TSMC is lower than that of SMC. That is, the MSE of SMC has triple MSE for each of joints in contrast with TSMC.

5. Conclusion

In this paper, we have designed a terminal sliding mode controller based on self recurrent wavelet neural network for nonlinear system with uncertainties. This terminal sliding mode control technique was used to improve performance, robustness, reliability and precision by contrast with classical sliding mode control. In addition, by using SRWNN, problem of systems such as uncertainties is solved easily. In our control system, the SRWNN having simple structure was used to estimate the unknown uncertainties and the nonlinear functions. The weights of SRWNN were trained by adaptation law based on the Lyapunov stability theorem which guarantee the stability of the designed control system. Finally, the computer simulation results showed the good tracking performance and the advantages of control method.

References

[1] J. J. Slotine and W. Li, Applied Nonlinear Control, Prentice-Hall, 1991.

[2] S. Tzafestas, M. Raibert and C. Tzafestas, "Robust Sliding-Mode Control Applied to a 5-link Biped Robot," Jour. of Intelligent and Robotics Systems, Vol. 15, No. 1, pp. 67-133, 1996.

[3] S. T. Venkataraman and S. Gulati, "Terminal Slider Control of Robot Systems," Jour. of Intelligent and Robotics Sysstems, Vol. 7, No. 1, pp. 31-55, 1993.

[4] K. H. Kyung, B. H. Lee and M. S. Ko, "Acceleration Based Learning Control of Robotic Manipulators Using a Multi-layered Neural Network," IEEE Trans. on Systems, Man and Cybernetics, Vol. 24, No. 8, pp. 1265-1272, 1994.

[5] M. J. Lee and Y. K. Choi, "An Adaptive Neurocontroller Using RBFN for Robot Manipulators," IEEE Trans. on Industrial Electronics, Vol. 51, No. 3, pp. 711-717, 2004.

[6] C. H. Kim, S. J. Yoo, J. B. Park and Y. H. Choi, "Sliding Mode Control of 5-link Biped Robot Using Wavelet Neural Network," Proc. of Int. Conf. on Control, Automation, and Systems (ICCAS), pp. 2279-2284, 2005.

[7] S. J. Yoo, Y. H. Choi and J. B. Park, "Generalized Predictive Control Based on Self Recurrent Wavelet Neural Network for Stable Path Tracking of Mobile Robots: Adaptive Learning Rates Approach," IEEE Trans. on Circuits and Systems I: Regular Papers, Vol. 53, No. 6, pp. 1381-1394, 2006.

Acknowledge

This work was supported by the Brain Korea 21 Project in 2006.