A Model Reference Adaptive Control Based on Fuzzy Neural Network for Some Weapon Ac Servo System

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Abstract. This paper presents a novel model reference adaptive control algorithm based on fuzzy neural network. This widely used method is utilized to adjust the parameters on line. The fuzzy neural network sliding mode controller,which integrates the fuzzy neural network with sliding mode controller, is put forward to control some weapon servo system with model uncertainties and parameters variation. Because this proposed algorithm combines excellences of FNN and sliding mode control, it has the ability to eliminate the drawbacks of traditional SMC, i.e. the chattering in the control signal and needing knowledge of bounds of uncertainties. Simulation results verify this proposed algorithm can reduce the plant's sensitivity to parameter variation and disturbance.
Keywords: ac servo system; position control; fuzzy neural network

1. Introduction:

Servo system has been frequently applied in position control of multiple rockets thanks to their ability of serving large driving forces, rapid response and so on. However, as a typical servo system, this weapon controller possesses lots of nonlinearities caused by mechanical friction and distortion of transmission shaft. In addition, there are some uncertain factors such as outer disturbances and unmodeling factors. In order to realize high performance control servo system, we should identify mathematical model of controlled object, i.e. system identification. As for nonlinear and time varying system, we often use adaptive control tactics because of difficult identification. In this paper, fuzzy neural network theory is applied to ac servo system for artellery. At the same time, combining with excellences of sliding mode control, a novel type control algorithm is put forward. Via simulation validation, model uncertainty and impact moment affection can effectively be overcome. The system has fairly good robustness, dynamic and static control precision, achieving satisfying control effects.

2. Model of pmsm servo system:

Vector control of ac pmsm is a kind of tactics based on magnetic field oriented method. During model derivation, we have some assumptions as follows:

$a.$ Ignoring saturation of central iron

$b.$ Ignoring bow wave and waste of stagnant magnet

$c.$ No damp roll thread in rotor and no damp effect in everlasting magnet

$d.$ Counter electromotive force is sine

Based on assumptions above, we can get state-space equation under $d - q$ rotate axes as follows:

$$\begin{bmatrix} \overset{\bullet}{i_d} \\ \overset{\bullet}{i_q} \\ \overset{\bullet}{\omega} \end{bmatrix} = \begin{bmatrix} -R/L & p\omega & 0 \\ p\omega & -R/L & -p\psi_r/L \\ 0 & p\psi_r/J & 0 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ \omega \end{bmatrix} + \begin{bmatrix} u_d/L \\ u_q/L \\ -T_l/J \end{bmatrix} \qquad (1)$$

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where, R is equivalent resistance of roll thread, L is equivalent inductance, p is the number of magnetic pole of electric motor, ω is mechanical angular velocity, ψ_r is flux of every pair magnetic pole, T_1 is load torque, and J is total moment of inertia at eletric motor shaft.

In this paper, we use $i_d \equiv 0$ decoupled control, so we can get

$$\begin{bmatrix} \dfrac{di_q}{dt} \\ \dfrac{d\omega}{dt} \\ \dfrac{d\theta}{dt} \end{bmatrix} = \begin{bmatrix} -R/L & -p\psi_r/L & 0 \\ p\psi_r/J & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_q \\ \omega \\ \theta \end{bmatrix} + \begin{bmatrix} u_q/L \\ -T_1/J \\ 0 \end{bmatrix} \tag{2}$$

Take angle θ and angular velocity ω as state variables, and let

$$X = \begin{bmatrix} \omega \\ \theta \end{bmatrix}, \quad A = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}, \quad B_1 = \begin{bmatrix} p\psi_r/J \\ 0 \end{bmatrix}, \quad B_2 = \begin{bmatrix} -\dfrac{1}{J} \\ 0 \end{bmatrix};$$

Take output as follows:

$$Y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} \omega \\ \theta \end{bmatrix}$$

Therefore, we can construct state-space equation of ac pmsm servo system as follows:

$$\begin{cases} \dot{X} = AX + B_1 i_q + B_2 T_1 \\ \quad Y = CX \end{cases} \tag{3}$$

Where A and B represent nominal model, traditional control adopts integration of PI controller and linear state feedback controller. But this method can't overcome bad effcets of model parameters' variation on performance. Therefore, a novel control algorithm is put forward to be applied to this weapon system. Simulation results show that this controller can make system have good following performance.

3. Design of SMC:

It is assumed that θ_d is the desired angle, and state variables are measurable and bound. The objective is to let θ track θ_d under condition of parameter variations and external disturbances. Define the tracking error $e_1 = \theta - \theta_d$, and the error vector

$$e = \begin{bmatrix} e_1 & e_2 \end{bmatrix}^T \tag{4}$$

Take

$$S = c_1 e_1 + e_2 \tag{5}$$

Where c_1, c_2 are constants. The sliding surface is

$$S = c_1 e_1 + e_2 = 0 \tag{6}$$

Set $\dot{S} = 0$, then the eqivalent control can be got as follows:

$$u_{equ} = \frac{J}{p\psi_r} \left(\frac{T_1}{J} - c_1 x_1 \right) \tag{7}$$

Then we can get the control principle as follows:

$$u = u_{equ} + u_N = u_{equ} + K \operatorname{sgn}(S) \tag{8}$$

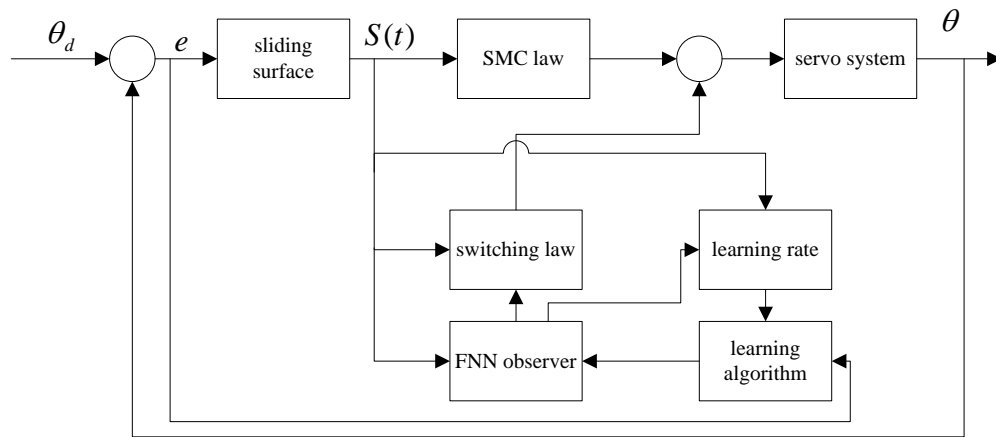## 4. Fuzzy neural network sliding mode control scheme:

Fig.1 Fuzzy neural network sliding mode control scheme

In this paper, a novel idea, i.e. fuzzy neural network sliding mode control is put forward to be applied in weapon servo system. The control principle is depicted in Fig.1. The inputs of FNN are S and $\dot{S}$, and the output is K.

5. Description of FC

The desired implement of fuzzy controller is as follows: according to the distance between state point and sliding mode line and its derivative, we can reason the output. The domains of S, $\dot{S}$ and u are chosen as [-5,5]. The fuzzy sets of S, $\dot{S}$ and u are chosen as [NB NM NS Z PS PM PB].

S	NB	NM	NS	Z	PS	PM	PB
$\dot{S}$	NB	NM	NS	Z	PS	PM	PB
u	NB	NM	NS	Z	PS	PM	PB

6. Description of FNN

A three-layer FNN is shown in Fig.2.

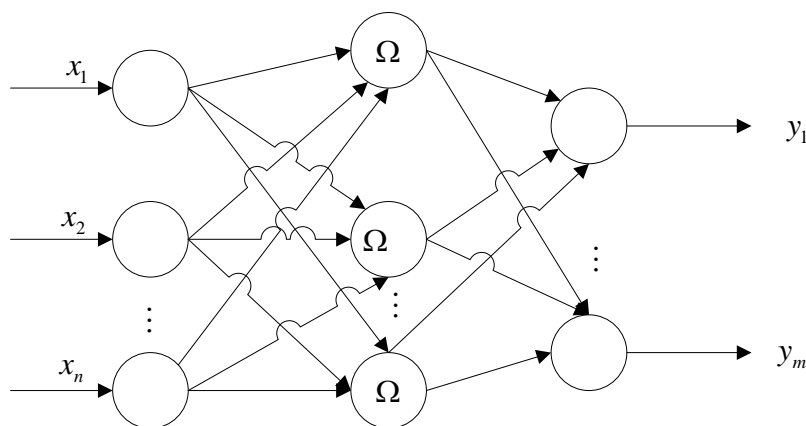Fig.2. Schematic diagram of FNN controller

Gaussian core function is expreesd as follows:

$$u_j = \exp\left(-\frac{(X - C_j)^T (X - C_j)}{2\sigma_j^{\,i}}\right), \quad j = 1,2,\cdots,N_n \qquad (9)$$

where, u_j is the jth output of hidden layer nodes, and $u_j \in [0,1]$, $X = (x_1, x_2, \cdots, x_n)^T$ are output samples. C_j is central value of Gaussian core function, σ_j is standard constant and N_n is the number of hidden layer nodes. Then, we get

$$y_i = \sum_{j=1}^{N_n} \omega_{ij} u_j - \theta = W_i^T U , \quad i = 1,2,\cdots,m \qquad (10)$$

where,

$$W_i = \left(\omega_{i1}, \omega_{i2}, \cdots, \omega_{iN_n}, -\theta\right)^T , \quad U = \left(u_1, u_2, \cdots, u_{N_n}, 1\right)^T \qquad (11)$$

Learning process of RBF neural network can be decomposed into two stages. At first, according to all input samples, central value of Gaussian core function C_j and standard constant σ_j are decided. Then, when parameters of hidden layer are decided, by use of the least two multiply theorem, weight value W_i of output layer is decided.

Theorem1: Given arbitrary $\varepsilon > 0$, for any L_2 type function $f : R^n \to R^m$, there exists an RBF neural network, it can approach f in arbitrary ε square error.

This theorem indicates that RBF neural network can approximate arbitrary continuous nonlinear function as BP neural network.

7. Identification algorithm:

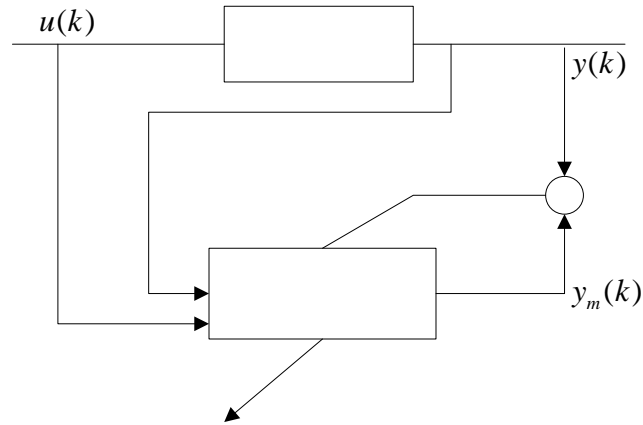Identification structure of RBF neural network is depicted as Fig.3.

Fig.3 RBF neural network approximation

In RBF network structure, $X = [x_1, x_2, \cdots, x_n]^T$ is input vector of network. Assume radial base $H = [h_1, h_2, \cdots, h_m]^T$, where h_j is Gaussian base function:

$$h_j = \exp\left(-\frac{\|X - c_j\|^2}{2b_j^{\,2}}\right) \quad j = 1,2,\cdots,m \qquad (12)$$

Where, central vector of the j th node is expressed as follows:

$$c_j = \left(c_{j1}, c_{j2}, \cdots, c_{jn}\right) \qquad (13)$$

Assume radial width vector of network is as follws:

$$B = [b_1, b_2, \cdots, b_m]^T \qquad (14)$$

Here, b_j is radial width parameter of node j, and $b_j > 0$. The weight vector of network is as follows:

$$W = [\omega_1, \omega_2, \cdots, \omega_m]^T \qquad (15)$$

Output of RBF neural network is expressed as follows:

$$y_m(t) = \omega_1 h_1 + \omega_2 h_2 + \cdots + \omega_m h_m \qquad (16)$$

Performance index function of RBF neural network is as follows:

$$E = \frac{1}{2}[y(t) - y_m(t)]^2 \qquad (17)$$

According to gradient descending method, iteration algorithms of output weight, node center and node base width parameter are expressed respectively as follows:

$$\omega_j(t) = \omega_j(t-1) + \eta[y(t) - y_m(t)]h_j + \alpha(\omega_j(t-1) - \omega_j(t-2)) \qquad (18)$$

$$\Delta b_j = [y(t) - y_m(t)]\omega_j h_j \frac{\|X - c_j\|^2}{b_j^3} \qquad (19)$$

$$b_j(t) = b_j(t-1) + \eta \Delta b_j + \alpha(b_j(t-1) - b_j(t-2)) \qquad (20)$$

$$\Delta c_{ji} = [y(t) - y_m(t)]\omega_j \frac{x_j - c_{ji}}{b_j^2} \qquad (21)$$

$$c_{ji}(t) = c_{ji}(t-1) + \eta \Delta c_{ji} + \alpha(c_{ji}(t-1) - c_{ji}(t-2)) \qquad (22)$$

Where, η is learning rate and α is momentum factor.

8. Design of FNNSMC

Fuzzy neural network, which incorporates excellences of fuzzy logic control and neural network control.

In order to obtain the inference control, BP algorithm is used to train parameters of FNN. Where, FNN is used to satisfy the conditions of sliding mode controller. We use neural networks in parallel to realize equivalent control and corrective control terms of sliding mode control.

RBF neural network is utlized to learn the outout and tune weights on line to make feedback control output appoximate zero, which makes neural network controller be leading. The value of the sliding mode function s can be gained from the prediction error vector e. Then the derivation $\dot{s}$ and s are fed back to the regulation function to assure the existence of sliding mode surface, i.e. $s \cdot \dot{s} < 0$.

9. Simulation results

In order to verify the validation of the proposed algorithm, the simulation experiment is carried out on orientation servo system. At the same time, in order to compare with traditional PID algorithm, simulation results under PID controller are shown as Fig.4, Fig.5 and Fig.6 respectively. The results under fuzzy neural network sliding mode controller are shown as Fig.7, Fig.8 and Fig.9 respectively. From the figures, we can find that when we use FNNSMC, the performance is better than PID controller. When we use the new algorithm proposed in this paper, we find that step response error curve is almost zero when the system reaches steady state, slope response error curve is less than 1mil and sine response error curve is less than 3mil，which fulfill the requests of the performance index.
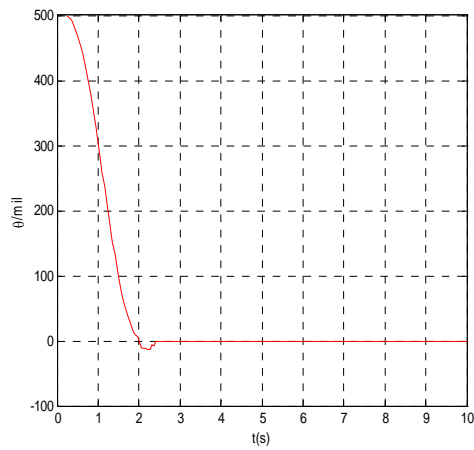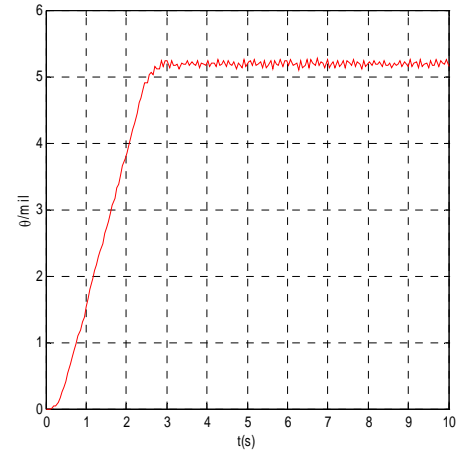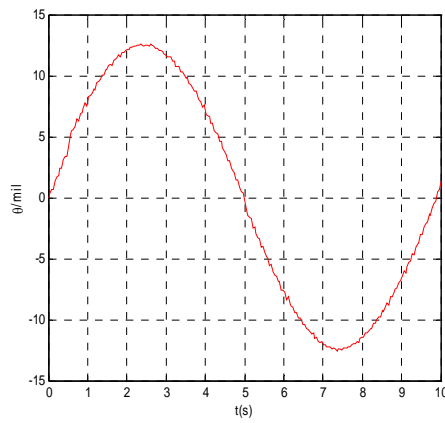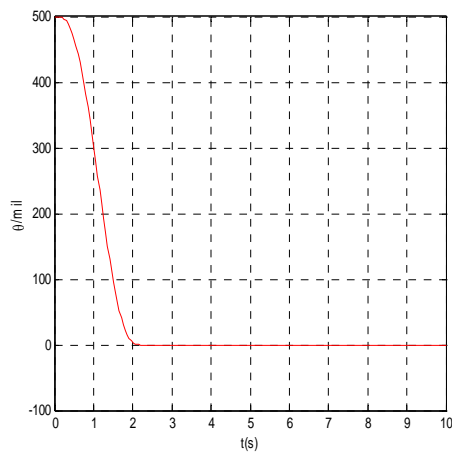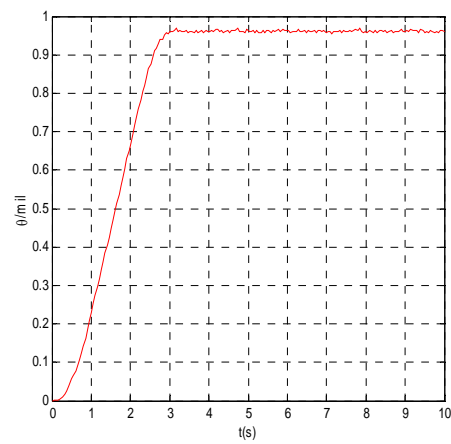
Fig.4 error curve of 500mil step reponse   Fig.5 error curve of $36^0/s$ slope response

Fig.6 error curve of 1042sin(7.86t)(mil) sine response

Fig.7 error curve of 500mil step reponse   Fig.8 error curve of $36^0/s$ slope response

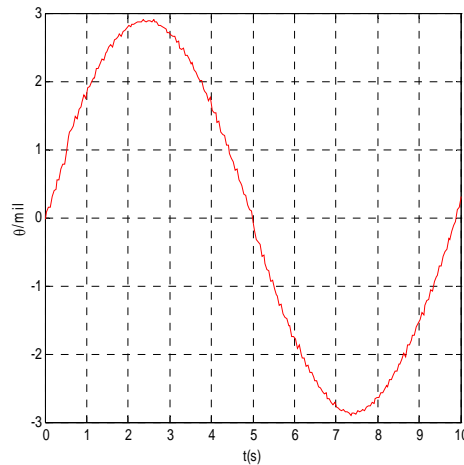Fig.9 error curve of 1042sin(7.86t)(mil) sine response

10.Acknowledgement

11.References:

[1]   Jun Wang, Hong Peng, and Xiao Jian.:Position Control for PM Synchronous Motor Using Fuzzy Neural Network. Springer-Verlag Berlin Heidelberg (2005) 179-184

[2]   Jin-kun Liu. MATLAB Simulation of Sliding Mode VSC. Beijing: Tsing Hua University Publishing House,2005,pp.188-218.

[3]   Huang S J, Huang K S,Chiou K C.Development and application of a novel radial basis function sliding mode controller. Mechatronics. 2003,13.

[4]   Chai HUAWEI. Robust Control and Application Research on Position Servo System of Some Cluster Antiaircraft Rocket Launcher. Phd,Nanjing University of Science and Technology,2008

[5]   Sira R H,Llanes S O.Adaptive dynamical sliding mode control via backstepping. Proceedings of the 32nd IEEE Conference on Decision and Control. February 1993.

[6]   Song J B, Ishida Y. A Robust Sliding Mode Control for Pneumatic Servo Systems. International Journal Engineering Science.1997,35(8):711-722

[7]   Wang SHITONG.Neural fuzzy system and its application. Beijing: Beijing University of Aeronautics and Astronautics,1998

[8]   Feipeng Da.Fuzzy neural network sliding mode control for long delay time systems based on fuzzy prediction.Neural Comput&Applic(2008)17:531-539

[9]   ZHANG Juli, WANG Xinmin, ZHANG Juzhong. Application of RBF Neutral Network and Fuzzy Control Combination in Motor Servo System. Micromotor,2007,40(5):39-41

[10] Ramirez HS,Morles EC(1995). A sliding mode strategy for adaptive learning in adalines. IEEE Trans Circuits Syst I 42:1001-1012

[11] HUANG Min, ZHU Qi-bing, CUI Bao-tong. Strip flatness and gauge decoupling predictive control based on wavelet neural networks. Control Theory & Applications.2008,25(6):1027-1036

[12] Richard JP(2003). Time-delay systems: an overview of some recent advances and open problems. Automatica 39: 1667-1694

[13] Guo Qing-ding, Wang Cheng-yuan. Ac Servo System[M]. Beijing: Machine Industry Publishing House,1993:92-100.

[14] Gomi and M.Kawato,Neural Network Control for a Closed-loop System Using Feedback-Error-Learning.Neural Networks, vol.6,1993.

[15] Douligeris C, Develekos G. Neural-fuzzy control in ATM networks. IEEE Communications Magazine,1997,(5).

[16] Young,K.K.D. Controller Design for a Manipulator Using Theory of Variable Structure Systems. IEEE Trans.

Systems,Man,and Cybernetics, Vol.SMC-8,1978(2).

[17] Ryan,E.A. Variable Structure Approach to Feedback Regulation of Uncertain Dynamical Systems. Int.J.Control,Vol.38,1983(6).

[18] Lehtomaki,N.A.,et al. Robustness and Modelling Error Characterization. IEEE Trans. Automatic Control.Vol. AC-29.1984(3).

[19] Doyle J C.Analysis of Feedback Systems with Structured Uncertainties. IEEE Proceedings.Part D.1982,129(6).

[20] Duan, S.L., An, G.C. Adaptive Sliding Mode Control for Electro-hydraulic Servo Force Control Systems. Chinese Jounal of Mechanical Engineering. 2002,38(5):109-113

[21] Zhu Yu-chuan.Research on Rapid Loading and High Precision Automatic Operating & Aiming System of a Certain Canister Multiple Rocket Launcher, Ph.D. Thesis. Nanjing University of Science & Technology,2006.

[22] ZHANG Jing-gang, LI Lin-sheng.A control method performed by a two-degree-of-freedom internal model. Industrial instrument and automatic equipment.2002,No.4:63-65

[23] ZHAO Zhi-cheng,JIA Yan-bin,ZHANG Jing-gang,SUN Zhi-yi.Design of an internal model controller for the electro-optical tracking system.Opto-Electronic Engineering.2005,Vol32,No.1:27-30