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Wavelet Neural Network Control System Based on Fuzzy PID

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Abstract: *Aiming at the network control system with time delay and packet loss, this paper designs a fuzzy adaptive PID controller to realize the adjustment of the network control system. Through the design of wavelet neural algorithm to predict the time delay, the fuzzy adaptive PID can realize the online adjustment of Kp, Ki and Kd, which overcomes the problem of constant input parameter adjustment of the traditional PID controller. Fuzzy control is realized by designing fuzzy rules, and finally through comparison The Matlab simulation renderings of traditional PID controller and fuzzy adaptive PID controller show that the robustness and accuracy of fuzzy adaptive PID controller are better.*

Keywords: *Network control system, fuzzy adaptive PID controller, wavelet neural network, time delay*

1. Introduction

The network control system is a new type of control system that has emerged with the development of network communication technology, computer information technology, and automatic control technology. It has the advantages of good real-time performance, easy expansion and maintenance, and high reliability. And network robots and other fields have good application prospects [1]. However, this system does not include delays caused by the network, packet loss, communication limitations, etc. In the design process of the control system, the above problems must be fully considered to avoid problems that cause controller instability [2]. In the design process of the control system, the above problems need to be fully considered to avoid the situation that causes the controller to lose stability. Reference [3] aimed at the problems of network delay and data packet loss, by setting up buffers to deal with data packet loss, and theoretically analyzed the fixed delay problem; Literature [4] analyzed the network with delay and deterministic packet loss Control the system and analyze the stability of the system. The above-mentioned documents only ideally deal with network delay and packet loss, but the robust performance of the system needs to be improved. Fuzzy adaptive PID control can adjust the accuracy of the system better. This makes fuzzy PID control an ideal choice for NCS designs that have problems such as network delays. Literature [5] proposed a control strategy that combines BP neural network and PI-IP control, which improves the response speed and control accuracy of the system. The fuzzy adaptive PID control strategy proposed [6] in improves the control accuracy and robustness of the system speed, but the time delay prediction is poor. Although the above-mentioned documents have advantages, but there are also areas for improvement. Wavelet neural network is a neural network model based on wavelet analysis theory. It does not depend on the precise model of the controlled object and makes full use of the good localization properties of wavelet transform. At the same time, combined with the self-learning function of the neural network, it has strong approximation and fault tolerance.

In response to the above problems, this paper presents a fuzzy PID adaptive controller to compensate for the loss of control data caused by mis-sequence and packet loss, thereby increasing the stability of the system.

2. Network control system structure and mathematical model

The structure of the network control system is mainly sensors, controllers, actuators, and controlled objects. Sensors and actuators are located at the output and input of the controlled object, and are connected to the input and output of the controller through a specific digital communication network. Connection, the network between the sensor and the controller is called the feedback channel [7], and the network between the controller and the actuator is called the feedforward channel. This article uses time-driven to design the sensor, it periodically takes output information from the controlled object y, and then combines it with the historical data in the data packet received by the actuator in the last cycle, plus the sampling time the timestamp Ts is packaged together and sent to the controller through the feedback channel [8]. The controller adopts an event-driven approach. It receives feedback data, executes control algorithms, and obtains control information u. It packs it together with the time stamp Ts in the feedback packet mentioned above and the time delay calculated from the last working cycle of the sensor, sent to the actuator via the forward channel [9]. The actuator is event-driven and has a logic judgment function. It first runs the data in the first control packet and calculates the delay of the packet [10] τ^{ca} and uses the control packet band The incoming Ts is marked to generate the basic τ^{ca} unit (τ^{ca}, Ts) of historical data.

Due to the irregular delay, packet loss, and out-of-sequence phenomena in the network control system [11], the state space of NCS can be expressed as follows:

$$\dot{x}(t) = ax(t-\tau^{sc}) + Bu(t-\tau^{ca}) \tag{1}$$

Where: $x(t) \in R^n$ is the state vector of the object, $u(t) \in R^m$ is the control input of the object. a, B, and C are constant matrices with appropriate dimensions. The independent variable $t = 1, 2, \dots$ is some positive integer.

3. Wavelet neural method to predict time delay

The structure of the wavelet neural network is shown in Figure 1, where is the input, is the predicted output, is the connection weight from the input layer to the hidden layer, and is the connection weight from the hidden layer to the output layer. Because wavelet neural network has high prediction accuracy and fitting effect, it can be used in network control system to predict the forward channel delay. Wavelet neural network is a neural network that combines wavelet analysis and BP neural network. On the basis of the BP neural network structure, the hidden layer nodes of the BP network are replaced by wavelet basis functions [12].

Hidden layer output:

$$q(j) = q_j\left(\frac{\sum_{i=1}^{k} w_{ij}x_i - b_j}{a_j}\right) \tag{2}$$

Where, $j = 1, 2, \cdots, l$

q_j is the wavelet basis function, b_j, a_j is the basis function parameter.

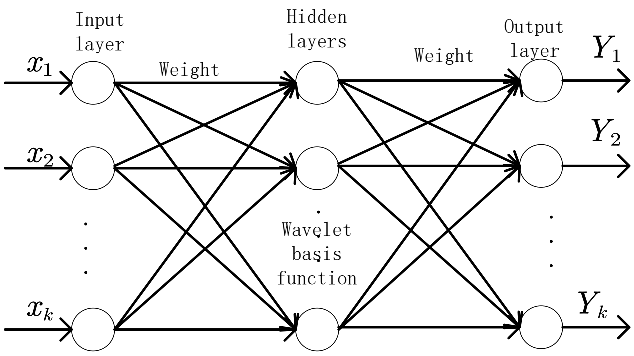

Figure 1: Structure diagram of wavelet neural network

The wavelet basis function is:

$$y = \cos(1.05x)e^{-x^2/2} \tag{3}$$

The output of the output layer is:

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$$q(k)=\sum_{j=1}^{l} w_{jk} q(j) \tag{4}$$

The training steps of the wavelet neural network algorithm are as follows [13]:Assign values to the wavelet basis function parameters and connection weights; Divide the measured network delay data into training samples and test samples, and then use the divided samples to train and test them; Use the training sample as the input value of the wavelet neural network and calculate the error between the predicted time delay and the real time delay; The gradient method is used to modify the weights and parameters to make the predicted value delay closer to the actual delay value.

4. PID controller design

The design of the PID controller consists of two parts, one is the design of the traditional PID controller, and the other is the design of the fuzzy adaptive PID controller.

4.1 Design of traditional PID controller

The traditional PID controller mainly includes proportional link, integral link and differential link. The traditional PID structure is shown in Figure 2.

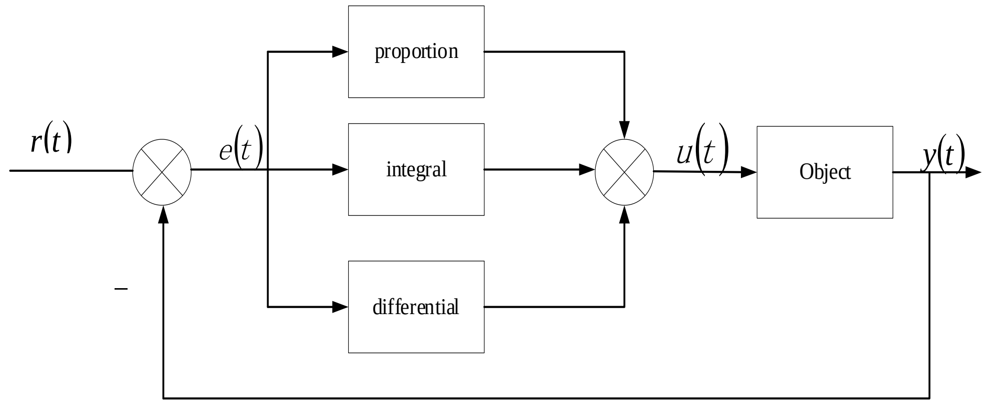

Figure 2: Schematic diagram of traditional PID control

In Figure 2, $r(t)$ is the given value, $y(t)$ is the system output, and $e(t)$ is the system deviation,

$$e(t)=r(t)-y(t) \tag{5}$$

The output expression of the PID controller is:

$$u(t)=K_p \cdot e(t)+K_i \int_0^t e(t)dt+K_d \frac{de(t)}{dt} \tag{6}$$

In the formula, K_p represents the proportional gain, K_i represents the integral gain, and K_d represents the differential gain. The PID adjusts the magnitude of these three parameters to meet the control requirements. The specific role of the PID parameters is as follows:

(1) Proportional gain K_p: Accelerate the response speed of the system and improve the adjustment accuracy of the system. The larger the K_p, the faster the response speed of the system, the higher the adjustment accuracy of the system, but the overshoot is likely to occur, and the system may be unstable. If the value of K_p is too small, the adjustment accuracy of the system will be lowered [14], the response speed will be slow, and the adjustment time will be prolonged, and the static and dynamic characteristics of the system will be deteriorated.

(2) Integral gain K_i : Eliminate the steady state error of the system. The larger the K_i is, the faster the static error of the system is eliminated, but the K_i is too large, and the integral saturation phenomenon occurs in the initial stage of the response process, which causes a large overshoot of the response process. If the K_i is too small, the static error of the system will be difficult to eliminate, which will affect the adjustment accuracy of the system.

(3) The function of the differential gain K_d is to improve the dynamic characteristics of the system.

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The function is to suppress the variation of the deviation in any direction during the response process, and predict the deviation in advance. However, if the K_d is too large, the response process will be braked in advance, thereby prolonging the adjustment time and reducing the anti-jamming performance of the system [14].

4.2 Fuzzy PID controller design

Fuzzy adaptive PID design process: according to the operational experience and strategy of the controlled object to write fuzzy rules; plus the input and output data of the controlled object is analyzed and organized to form a fuzzy control library, through the selected input and output, membership function, fuzzy Subset, determine fuzzy rules, design a fuzzy controller . Discrete fuzzy PID control algorithm is

$$u(k) = K_p e(k) + K_i T \sum_{j=0}^{k} e(j) + K_d \frac{e(k)-e(k-1)}{T} \tag{7}$$

In the formula, $u(k)$ is the controller output, K_p is the proportional coefficient, K_i is the integral coefficient, K_d is the differential coefficient, $e(k)$ is the system deviation, k is the sampling number, and T is the sampling time. The fuzzy PID control is used to control the furnace temperature. The working principle is as follows: the adaptive fuzzy PID controller controls the object, and the fuzzy controller can adjust the parameters of the PID controller in real time, and simultaneously collect the deviation e and deviation of the visual sensor. The rate of change ec is used as the input of the fuzzy controller. The fuzzy rule is used for fuzzy reasoning. The online correction of K_p, K_i and K_d is carried out, and the modified parameter values are brought into the system to replace the old parameter values. The purpose of the system control block diagram is shown in Figure 3.

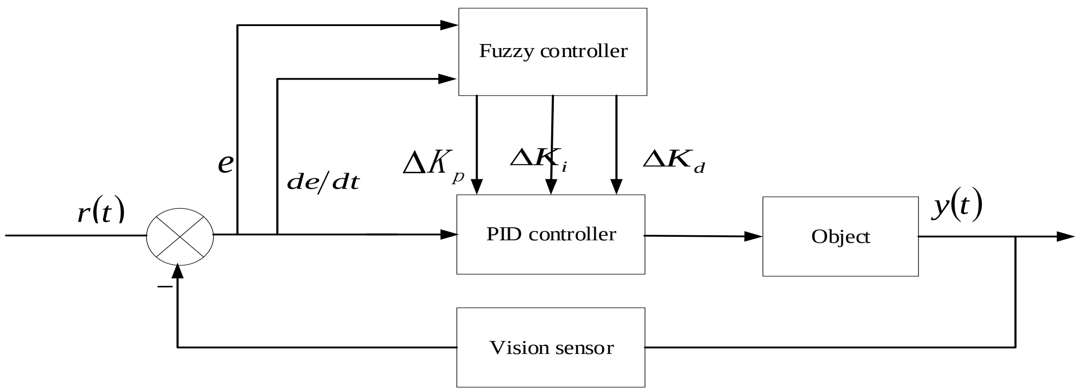

Figure 3: Principle of adaptive fuzzy PID controller

In this paper, a two-input and three-output two-dimensional fuzzy PID controller is used to blur the deviation signal e and the rotational speed deviation rate ec obtained by comparing the room temperature with the reference value, and the fuzzy variables E and EC can be obtained. For the output variable K_p, K_i and K_d, comprehensively consider the system's stability overshoot response speed and steady-state error, etc., combined with the changes of parameters$|E|$and$|EC|$in the controlled process, in order to make the system stable, the PID parameters self-tuning principles are as follows [15]:

When the value of $|E|$ is small, the values of ΔK_p and ΔK_i should be larger to avoid large oscillations in the system. When the $|EC|$ is small, the value of ΔK_d is larger;

When the value of $|E|$ is larger than When large, the values of ΔK_p and ΔK_i should be smaller to reduce the system overshoot. The triangle membership function is selected in Matlab's own toolbox to achieve fuzzy. The input and output variable ranges are set at$[-3,3]$, let the fuzzy subset of its domain be $\{NB, NM, NS, NO, PS, PM, PB\}$and the meaning of each element in it {negative big, negative medium, negative small, zero, small, medium, big} Combine relevant theories and refer to the actual temperature measurement experience to establish the fuzzy inference rules from Table 1 to Table 3.

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Table 1: ΔK_p fuzzy rule table

ec	e						
	NB	NS	NM	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	ZO
NM	NB	NM	NM	NS	NS	ZO	PS
NS	NM	NM	NS	NS	ZO	PS	PS
ZO	NM	NS	NS	ZO	PS	PS	PM
PS	NS	NS	ZO	PS	PS	PM	PM
PM	NS	ZO	PS	PS	PM	PM	PB
PB	ZO	PS	PS	PM	PM	PB	PB

Table 2: ΔK_i fuzzy rule table

ec	e						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	ZO
NM	PB	PB	PM	PM	PS	ZO	NS
NS	PM	PM	PS	PS	ZO	NS	NS
ZO	PM	PS	PS	ZO	NS	NS	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NS	NM	NM	NB
PB	ZO	NS	NS	NM	NB	NB	NB

Table 3: ΔK_d fuzzy rule table

ec	e						
	NB	NS	NM	ZO	PS	PM	PB
NB	PB	ZO	ZO	PS	PS	PB	PB
NM	NS	NS	NS	ZO	PS	PS	PB
NS	NB	NB	NM	ZO	ZO	PS	PM
ZO	NB	NM	NM	ZO	NS	PS	PM
PS	NB	NM	NS	ZO	NS	PS	PS
PM	NM	NS	NS	ZO	NM	PS	PS
PB	PS	ZO	ZO	PS	ZO	PB	PB

From Table 1 to Table 3, the range of the domain of e, ec, ΔK_p, ΔK_i and ΔK_d, taking into account the principle of robustness of the system, the fuzzy subset of each parameter and variable is in the form of a triangular membership function. According to the actual values of e and ec, the adjustment amount of the fuzzy set at each moment is determined, and the PID is adjusted online in real time. The parameters of the controller, so that the parameters corrected at the next moment are obtained.

$$\begin{cases} K_P = K_{P0} + \Delta K_P \\ K_i = K_{i0} + \Delta K_i \\ K_d = K_{d0} + \Delta K_d \end{cases} \tag{8}$$

Where K_{p0}, K_{i0} and K_{d0} represent the determined portion, ΔK_p, ΔK_i and ΔK_d represent the adjusted portion after fuzzy control.

5. Matlab simulation and result analysis

The simulation verification is carried out using MATLAB's network control system simulation platform TrueTime2.0. Consider building the following system. The transfer function of the object is:

$$G(s) = \frac{1.8}{150s+1} \cdot e^{-30S}$$

In the model, the system sampling interval is T =10ms, the network uses the Can network protocol, that is, the order of information transmission is determined according to the priority, and the data transmission rate is 80000 (b/s). To verify the method in this article, the packet loss rate is set to 5%. Among them, Kp=1.8, Ki=0.015 and Kd=22.5 According to the designed fuzzy controller, the membership functions of ΔK_p, ΔK_i and ΔK_d.

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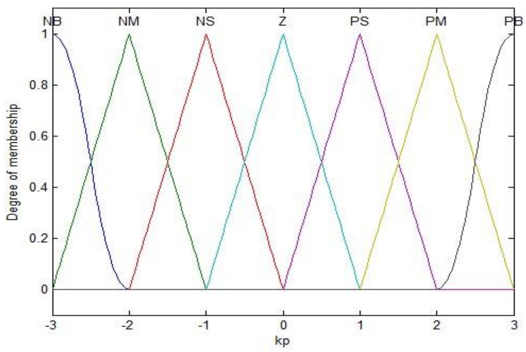

Figure 4: ΔK_pMembership function

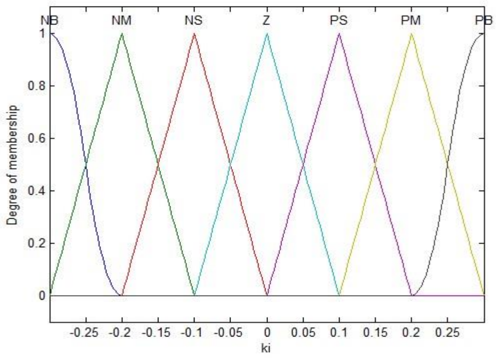

Figure 5: ΔK_iMembership function

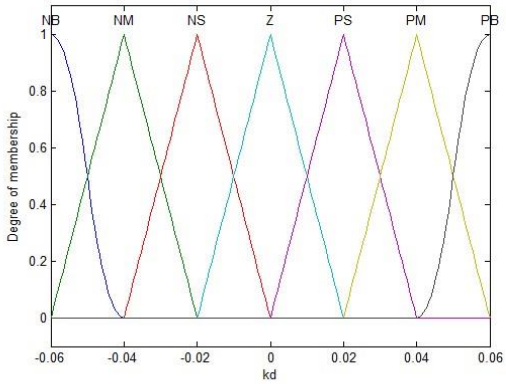

Figure 6: ΔK_dMembership function

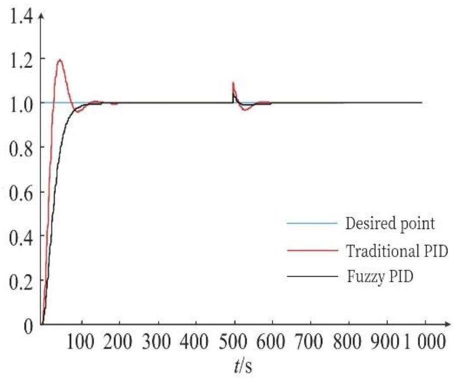

Figure 7: Simulation results

The simulation results can be seen from the figure. The traditional PID method is affected by the network delay and packet loss. The output y has a large overshoot, is unstable, and the tracking effect is poor, which cannot meet the control performance requirements. Keeping the same object parameters, compared with the traditional PID method, after adopting the method in this paper, the system has better robustness and system tracking ability, compensates for the influence of network delay and packet loss, and ensures the rapid stability of the system, whether it is super Both the adjustment time and the response time can meet the control performance requirements. At t=500s, adding a disturbance, it can be observed that the fuzzy PID can recover faster, indicating that its robustness is better.

6. Conclusion

This article discusses the problems of time delay and packet loss in network control systems. The first is to establish a network control system model. Secondly, the wavelet neural network is used to predict the network delay, and the fuzzy PID control reasoning rules are designed. Finally, a fuzzy adaptive PID controller is designed, which uses the predicted control signal sequence to compensate for time delay and data packet loss. Finally, simulations verify the effectiveness and robustness of the method.

References

[1] Lu Qing. Research on predictive control of networked control systems [D]. Bohai University, 2016.
[2] Wu Jie, Fu Jingqi. Collaborative design of event triggering and quantitative control for networked control systems [J]. Electronic Measurement Technology, 2017, 40(05): 80-86.
[3] Tang Xiaoming, Deng Li, Yu Jimin, et al. Output feedback predictive control of networked control system based on interval two T-S fuzzy model [J]. Acta Automatica Sinica, 2019, v.45 (03): 162-174.
[4] YING Z, HU S. H infinity control for DC servo motor in the network environment [C] //2015 IEEE Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), IEEE, 2015.
[5] Jing S, Guo S, Zhao X, et al. BP neural network PID controller of pocket dropout [C] // IEEE International Conference on Computer & Communications. IEEE, 2016.
[6] Duan Kun, Lu Meng. Fuzzy control and fuzzy adaptive PID control of mobile robots [J]. Electronic

ISSN 2616-5775 Vol. 4, Issue 3: 18-24, DOI: 10.25236/AJCIS.2021.040303

Test, 2019.

[7] Wang R, Duan R. Research and Simulation of Network Control System Smith Estimating PSD Control [J]. Journal of Physics: Conference Series, 2021, 1846(1):012085 (8pp).

[8] FEDOR, Y., CHEMASHKIN, et al. Problems in Network Control Systems and their Solutions [C] //2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), IEEE, 2019.

[9] Zhang Hao, Peng Chen, Sun Hongtao. Research on the Stability of Multi-path Wireless Network Control System [J]. Journal of Electronic Measurement and Instrument, 2016, 30(11): 1627-1634.

[10] ZHANG Y, XIE S, REN L, et al. A new predictive sliding mode control approach for networked control systems with time delay and packet dropout [J]. IEEE Access, 2019, PP (99): 1-1.

[11] Li Junhui, Lu Jieying, Su Weizhou. Mean Square Stabilization Analysis of Network Control System with Random Delay [J]. Control and Decision, 2020, v.35 (04): 178-183.

[12] Xie Dong, Zhang Xing, Cao Renxian. Island detection technology based on wavelet transform and neural network [J]. Proceedings of the CSEE, 2014, 34(4): 537-544.

[13] Luo Yongping. Research on Time Delay Prediction and Compensation Control of Network Control System [D]. Zhengzhou University.

[14] Peng Y, Luo J, Zhuang J, et al. Model reference fuzzy adaptive PID control and its applications in typical industrial processes [C] //2008 IEEE International Conference on Automation and Logistics. IEEE, 2008: 896-901.

[15] Yao G, Gao F, Wang C, et al. Design and simulation based on Kalman filter fuzzy adaptive PID control for mold liquid level control system [C] //2009 Chinese Control and Decision Conference. IEEE, 2009: 6105-6109.