International Journal of Grid and Distributed Computing
Vol. 9, No. 3 (2016), pp.117-124
http://dx.doi.org/10.14257/ijgdc.2016.9.3.14

The Design of Fuzzy PID Controller for Networked Systems with Random Time Delay

Fang Liu[1], Fenglin Li[2] and Dandan Xiao[3]

Wuhan Technology and Business University, WuHan 430063, China;
liufangteacher1982@126.com

Abstract

In this paper, the nonlinear systems with time delay network control is discussed transmission delays and packet dropouts for networked control system with random time delay are analyzed. In this paper, online delay estimation method to obtain the delay value, the delay value is an input parameter of fuzzy adaptive PID controller, fuzzy PID temporal adjustment based on genetic algorithm and Particle swarm optimization algorithm to optimization objective function, three parameters of PID is adjusted Online in order to improve the system stability, through Matlab co-simulation tool True Time, the shows the fuzzy logic control system base on PSO algorithm promote reduce transmission delays and packet dropouts. The paper also shows the superiority of Fuzzy PID controllers over their traditional PID for NCS applications.

***Keywords**: Networked Control System, Fuzzy PID, GA, PSO, Optimal PID Tuning*

1. Introduction

The issues of stochastically varying network delays and packet dropouts in Networked Control System (NCS) applications have been addressed by time domain optimal tuning of Fuzzy PID controllers. Network communication control system is introduced into the loop feedback control system, a feedback control system formed by a network is called Networked Control Systems (NCS) [1], In particular, delays introduced by the network and packet dropouts are of prime concern while assessing the control loop performance. In this paper, the complex time delay is changed into a single delay in this networked control systems. A fuzzy adaptive PID controller is designed for networked control systems with time delay. The optimization based on genetic algorithm and Particle swarm optimization algorithm. According to adjusted PID three parameters online, the proposed controller is better than the conventional PID controller with three parameters, such as low overshoot, small oscillation, short response time, and significantly improve the system performance.

2. PID Controller

2.1 PID Controller and Fuzzy PID Controller

The traditional PID is adjusted by the three parameters's combination of proportional, integral and differential. PID algorithm has good performance only in the non-time-varying system, but Fuzzy-PID has some adaptive capacity to the band lag, nonlinear and time-varying system. Meanwhile, Fuzzy-PID control system error (e)and error derivative ($\dot{e}$) as input parameters, the Fuzzy-PID combined with the advantages of PID and Fuzzy control in order to achieve good control effect[2]. Figure 1 shows the structure of the fuzzy self-tuning PID parameters of the network controller. The controller output of a

ISSN: 2005-4262 IJGDC

conventional PID is a weighted sum of error, its derivative and integral values, add a fuzzy PID parameter regulator, and the output expression of the system is

$$u(t) = K_P e(t) + k_I \int_0^t e(t)dt + k_D \frac{de(t)}{dt} \quad (1)$$

Fuzzy PID controllers have been studied in this paper, considering the combinations of hybrid controllers by grouping the proportional, integral and derivative actions with fuzzy inferencing .The input and output scaling factors (SF) along with the integro-differential operators are tuned with real coded GA and PSO, to produce optimum closed loop performance by simultaneous consideration of the control loop error index and the control signal.

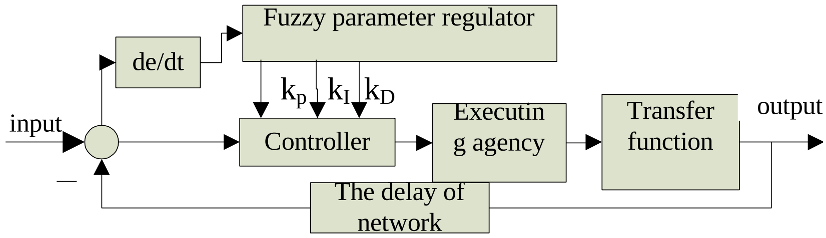

Figure 1. Fuzzy PID Control Structure Diagram

The nonlinear process of the fuzzy controller can be achieved, through the application of Fuzzy Logic Control to improve the closed-loop PID controller, but there are no mathematical formulation to decide how to choice the fuzzy parameters, so the empirical rule is used and derived from expert's knowledge. In this study, the input and output parameters are adjusted to find the Fuzzy Logic controller to handle network delay. Through the application of random optimal parameter variation fuzzy reasoning mechanism, the parameters involved in the literature [3] has been studied.

2.2 The Fuzzy PID Logic Controller in Random Time Delay Network

In the communication system, such as Ethernet or CAN bus and other transmission channels has been widely used as the public communication, network control system reduce the routing costs, eliminate the special maintenance communication channels, achieve resource sharing. There is a problem of transmission delays and packet dropouts, random variation in network delay with time, which can reduce the control performance. In NCS, the network delay is the main factor causing the system performance degradation, the network delay is variable with time, which brings many difficulties to the controller design in NCS. In recent studies, the application of NCS based on fuzzy logic controller is proved to be effective in dealing with the problems caused by transmission delays and packet dropouts. Lee et al. [4] through the application of genetic algorithm and fuzzy logic， to analysis the network environment NCS controller design and simulation experiments, however, these methods and controller can not adjust the parameters of the controller online. In the nonlinear time varying systems, the FLCs have the ability to enforce the optimal performance of the PID in the control loop of the nonlinear time varying systems [5].

3. System Model Analysis

3.1 Fuzzy PID Controller Model of Random Time Delay M=Network

The delay of the loop network system mainly includes two parts: one is that sensor to controller delay τ^{sc}; the second is the controller to actuator delayτ^{ca}. The process of through the network may are treated as random time delay system, in this study, distributed delay is reduced for the single time delay, which can greatly reduce the design difficulty of controller system [6]. In this paper, a new fuzzy adaptive controller is designed by using the method of on-line time delay estimation, and a new type fuzzy PID controller is designed, which is based on proportional, integral and differential. Fuzzy PID controller model for random time delay network is shown in the Figue.2.

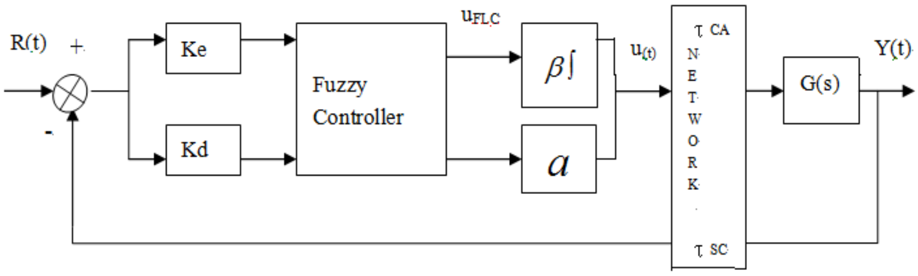

Figure 2. Fuzzy PID Control Diagram of Random Time Delay Network

3.2 Improvement of Fuzzy PID Controller Model for Random Time Delay Network

The traditional fuzzy PID control has three inputs and three dimensional rule base, Further optimization controller is proposed by Woo et al.[7], Using two input and two dimensional rule base, through the design of membership functions and self -adjustment scale factor to achieve control objectives. The fuzzy PID structure is a combination of fuzzy PI and fuzzy PD controllers with K_e, K_d as input scaling factors, and α, β as output scaling factors. This two-dimensional linear rule base for error (e), error derivative ($\dot{e}$), the FLC output (u_{FLC}) with standard triangular and Mamdanitype inferencing. The Operation rule is "if e is ? and e_c is ? then u is ?", At the same time to establish their own fuzzy rule set. The output of the network control system with Random time delay is

$$u_{FLC}(t) = K_P e(t) + k_I \int_0^t e(t)dt + k_D \frac{de(t)}{dt} \tag{2}$$

$$u(t) = \alpha(A + PK_e e + DKd\dot{e}) + \beta \int_0^t (A + PK_e e + DKd\dot{e})dt \tag{3}$$

$$u(t) = \alpha u_{FLC} + \beta \int_0^t u_{FLC}(t)dt \tag{4}$$

4. Parameter Parameter Optimization of Fuzzy Controller Based on Genetic Algorithm & Particle Swarm Optimization Algorithm

4.1 Phe Parameter Optimizing of Fuzzy PID Controller Base on Genetic Algorithm [8]

PID based on Genetic algorithm networks controller with delay has many advanced properties compared with traditional PID. Genetic algorithm is a stochastic optimization procedure, based on the process of natural biological evolution, which is the method of finding the global optimal direction in the problem solving space [9], which includes three steps: selection, crossover and mutation, In order to select the high practical individual. Individuals randomly select a cross site to generate a new sample; increase the search space is to prevent the loss of important genetic information. Crossover refers to information exchange between solution vectors based on probabilistic decisions .the crossover in each iteration, a certain percentage of the population exchange information among them to give rise to fitter solution vectors. The Mutation, a randomly selected portion is sometimes altered to yield fitter individuals. To give rise to a better method of solution vectors in the next iteration. In this paper the mutation fraction is 0.2 and the crossover fraction is 0.8. In each generation, the objective function can be evaluated for each of the individuals in parallel since these evaluations are not dependent on the evaluation of other individuals in the current generation, This way of solution is order to refined iteratively until the objective function is minimized .Parameter optimization is produces a set of candidate solution in the allowable range , binary code used in this design, the parameters encoded to form a string, The chromosome string is comprised of string .In this study , the crossover and mutation fraction needs to be used.

4.2 The Parameter Optimizing of Fuzzy PID Controller Base on Particle Swarm Optimization Algorithm

In PSO, the solution of the optimization problem is considered as the particle in the search space, and all the particles have an adaptive value which is determined by the optimization function. The bjective function which is to be minimized s used to evaluate the fitness of the particle for a particular position. For each particle the velocity in each dimension in he consecutive iteration is updated by the following velocity and osition update equation,

$$v_i(t+1) = \omega v_i(t) + c_1\varphi_1(pi(t) - xi(t)) + c_2\varphi_2(pg(t) - xi(t)) \quad (5)$$

$$x_i(t+1) = x_i(t) + v_i(t+1). \quad (6)$$

given by Jun Sum proposed the Quantum Particle swarm optimization (QPSO) algorithm in 2004, Karaboga proposed the ABC algorithm (artificial bee colony algorithm) in 2005, ABC algorithm leading peak in find nectar accessories are new nectar search, based on the analysis of the literature [10], ABC search mutation operator, guidance formula jump out of the local optimization, avoid premature convergence.

4.3 Timization of the Objective Function for Time Domain Integral Performance Index Based Tuning of Networked Process Controllers

The performance of the optimal controller is also determined by a suitable optimization algorithm, which is used to adjust the controller. Selecting the objective function, the performance of the target function can be relatively accurate. The objective function J is minimized to find out the optimal setting value of controller parameters, which reduces the ITAE and control signal u (t) [11]. In time domain performance metrics, the unit step input is given, ITAE generates a much smaller overshoot and shorter rise time than ITSE, so in this study ITAE be used. The objective function is the sum of the weighted sum of the error and the control signal square. The weights W_1 and W_2 have been reflected in the objective function. In the study of the simulation, the balance error and the control signal have equal weight that is W_1=W_2, the objective function's mathematical expression is

$$J = \int_0^{\infty} [w_1 te(t) + w_2 u^2(t)]dt \quad (8)$$

the objective function (5) will get different values depending on the time instants of packet arrival, which have the same set of controller parameters of stochastically varying delays and packet-drops in the network. Hence, the objective function for time domain optimal controller tuning is stochastic and must be handled [12]. The Figure.3 show the stochastically varying difference between a smooth time invariant representative objective function and its corresponding rough.

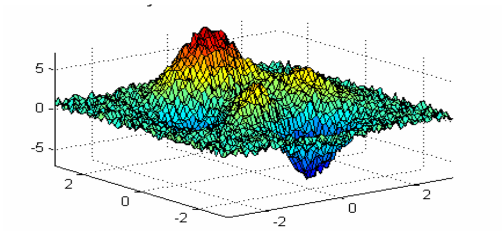

Figure 3. Rough Stochastically Varying Objective Function

4.4 Operation of Genetic Algorithm Parameters.

In this study, the size of the population is M, and the fitness of the individual is Fi, then the probability of its selection is Pi. The running parameters of the number of ethnic groups Size are iterated; crossover and mutation, and the parameters have a great influence on the shrinkage rate and performance. When the number of Size is too small, the convergence is premature; but the number of groups is too large, the computation becomes complex. The new individual is introduced; it may destroy the high performance individuals when the probability of Pc is too large; it also will affect the convergence premature when the probability of Pc is too small. Mutation probability Pm is similar crossover probability Pc in this study, the number of ethnic groups Size=20, the elite number is 2.simulation we have used the crossover fraction to be 0.8 and mutation fraction to be 0.2 which can bring satisfactory results.

4.5 Operation of Particle Swarm Optimization Algorithm

PSO optimization algorithm reflects the personality and sociality of particles, in the above formula (5), the particles due to the past position and speed of the current, the impact factor is ω.Each particle's position (x_i) in the next iteration depends onits velocity (v_i) in the present equation multiplied by an inertia factor (ω); The cognitive part of the particles, the influence factors are expressed by C_1; the learning part of the particles, the influence factors are expressed by C_2. Weights $C_1 = C_2$, the C_1 C_2 are generally from 1-4, in this study c1=c2=2, represent the relative importance of the learning of the particles to [13], {φ1, φ2} ∈ [0, 1] are two uniformly distributedrandom numbers. (ω) in the iterative process, optimize the search space, accelerate the search speed,in test,the inertia factor (ω) reduced linearly from 0.9 to 0.4 over the iterations.

5. Simulation Results

MATLAB simulation study of a NCS with packet dropout and radom delay,the communication network is actually a control loop system, In this case MATLAB Simulink [14-15] is used for the continuous time plant .in this simulations, the sampling time is assumed to be 0.01 seconds. When the delay of each packet is less than 0.01 seconds , the sequence of the packets are maintained, but when the delays are greater than one sampling period, then the packets arrive out of sequence. The closed loop system with random time delay, its transfer function

$$T(s) = \frac{(s+3)e^{-0.1s}}{(s+1)(4s+1)}$$

The system input is a unit step function, the output value of the network delay system is observed by the PID controller, The correlation parameters of the traditional PID and fuzzy PID controller respectively are obtained by GA and QPSO respectively. The value of the online tuning proportional integral differential, the control parameter is calculated by minimizing the objective function. The value is shown without delay in Table 1; the value with delay is shown in Table 2.

Table 1. On-line Setting Value without Delay

transfer function	Optimization algorithm	the objective function J_{min}	Ke	Kd	a	b
$T(s) = \frac{(s+2)e^{-0.1s}}{(s+1)(4s+1)}$	genetic algorithm	14.52	0.85	0.53	3.08	0.77
	Particle swarm optimization algorithm	55.25	0.44	0.55	1.51	0.63

Table 2. On-Line Setting Value with Delay

transfer function	Optimization algorithm	the objective function J_{min}	Ke	Kd	a	b
$T(s) = \frac{(s+2)e^{-0.1s}}{(s+1)(4s+1)}$	genetic algorithm	14.92	1.93	1.08	1.92	0.73
	Particle swarm optimization algorithm	55.34	0.45	0.61	1.49	0.65

The corresponding output of the Simlink is shown in Figure 4.

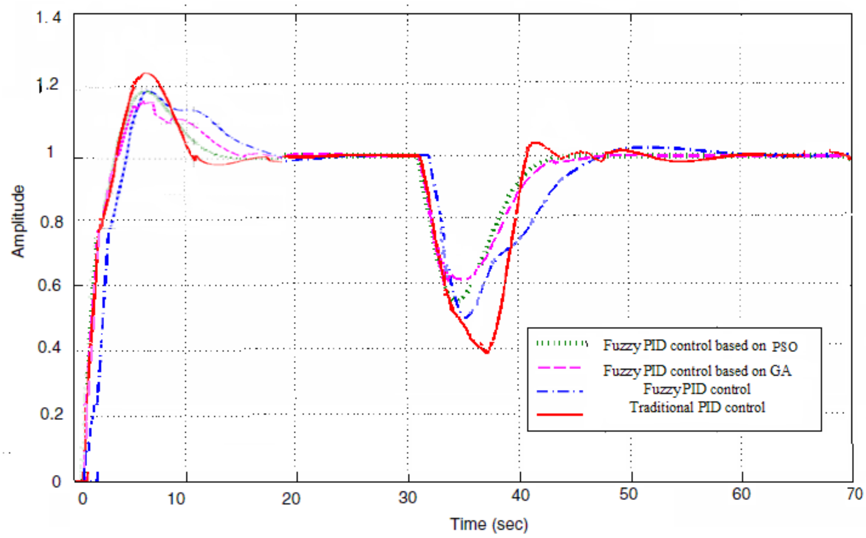

Figure 4. Step Response Simulation of Random Delay Network Unit

6. Summary

In this paper, the NCS network with random time delay is analyzed by fuzzy PID controller, and the optimization of ITAE is adjusted by using the genetic algorithm. In NCS system, Simulation results indicate that the effectiveness of Fuzzy PID Control Systems Base on Genetic algorithms and Particle swarm optimization algorithm is superior to the traditional PID control algorithm, the PSO is better than GA. the fuzzy adaptive PID control algorithm; The system stability is high, the overshoot is small, the time is short; And this controller is superior in the dynamic character of system. At the same time, the system can reduce transmission delays and packet dropouts.The Fuzzy PID controllers are tuned for time domain optimality criterion with GA and PSO to handle the adverse effects of stochastic variation of network delay and packet dropouts.

Acknowledgements

In this study, thanks to the support of the Information Engineering Institute of *Wuhan Technology and Business University*, thanks to the joint efforts of our team.

References

[1] W Yuzhen, H Xiaofang, W Airong, "A class of actuator saturation nonlinear Hamilton network control system controller design [J]". Journal of Shandong University (Engineering Edition). **(2014)** no. 01, pp. 151-159.
[2] S Xiaoqian, you Rui Huang, song Liguo. Based on RBF neural network PID control of wireless network delay control, industrial automation, **(2013)**, vol. 12, pp. 47-49.
[3] B Hamid, TMohamed, G Pierre-Yves, L Salim, "Tuning fuzzy PD and PI controllers using reinforcement learning". ISA Transactions, vol. 49, no. 4, **(2010)**, pp. 543–51.
[4] C Huang, Y Bai and X Li, "Simulation for a class of networked cascade control systems by PID control", International Conference on Networking, Sensing and Control (ICNSC), **(2010)**, pp. 458-463, April 2010, Chicago.
[5] J Xinchun, Z Dawei, H Xinghua, Z Nanning. Fuzzy H tracking control for nonlinear networked control systems in T–S fuzzy model. IEEETransactions on Systems, Man and Cybernetics, Part B (Cybernetics) vol. 39, no. 4, **(2009)**,pp. 1073–9.
[6] G Xiaoqian, "network control system's time delay analysis and PID controller design", Beijing Jiaotong University, 2010, master's thesis.
[7] W Zhi-Wei, C Hung-Yuan, L Jin-Jye., "A PID type fuzzy controller with self-tuning scaling factors". Fuzzy Sets and Systems 2000; vol. 115, no. 2, pp. 321–6.
[8] "Global optimization toolbox: user's guide," Mathworks, Inc., 2010.
[9] Z Yinghe, H Wei. Parameter optimization of fuzzy PID controller based on adaptive genetic algorithm, Journal of Hangzhou Dianzi University, **(2011)**, no. 31, pp. 58-63.
[10] YZhenhua, NXialin, L Zong gun, "Fuzzy adaptive PID control of networked control systems, Journal of Fuzhou University", [J], vol. (10), **(2012)**, pp. 99-122.
[11] A Cuenca, JSalt, A Sala and R Piza, "A delay-dependent dual-rate PID controller over an ethernet network", IEEE Transactions on Industrial Informatics, vol. 7, no. 1, pp. 18-29, February **(2011)**.
[12] I Pan, S Das, and A Gupta,"Handling Packet Dropouts and Random Delays for Unstable Delayed Processes in NCS by Optimal Tuning of PIλDμ Controllers with Evolutionary" ,Algorithms, ISA Transactions**(2012)**; vol. 49, no. 4, pp. 543–51.
[13] H Kita and Y Sano, "Genetic algorithms for optimization of noisy fitness functions and adaptation to changing environments", SICE 2003 Annual Conference, vol. 3, pp. 2744-2749, August 2003, Fukui, Japan.
[14] "Simulink: user's guide," Mathworks, Inc., **(2010)**.
[15] "SimEvents: user's guide," Mathworks, Inc., **(2010)**.
[16] W Li,X Cai, "Tuning of an optimal fuzzy NCS controller parameters based on the improved quantum particle swarm", application Research of computer,vol 30(8),Aug **(2013)**, pp. 165-172.

Authors

Fang Liu, She earned her Bachelor degree in automation in 2004. Master degree in electronic information engineering in 2009. Lecturer, director of the Department of networking engineering, the current research direction for the sensor and sensor network, automatic control.

Fenglin Li, She earned her Bachelor degree in Computer application in 2002. Master degree in Computer application in 2009. Lecturer, teacher of the Department of networking engineering, the current research direction for Computer network.

Dandan Xiao, She earned her Bachelor degree in Biomedical Engineering in 2005. Master degree in Signal detection and processing in 2009. Lecturer, teacher of the Department of networking engineering, the current research direction for the algorithm analysis, signal processing.