The Design of Fuzzy PID Delay Networked Control Systems Based on Genetic Algorithms

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Abstract. The nonlinear systems with time delay network control is discussed in this paper, transmission delays and packet dropouts for networked control system with random time delay is 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 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 promote reduce transmission delays and packet dropouts.

1. Introduction

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 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. be optimization based on genetic 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 (˙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 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

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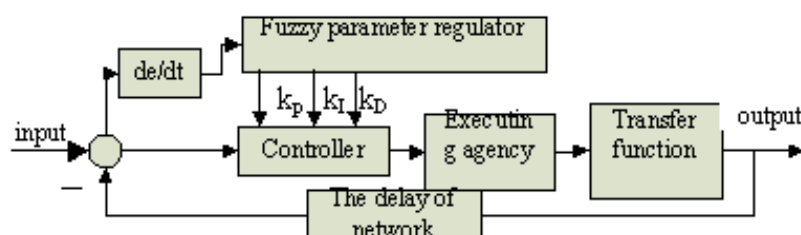

Fig. 1 Fuzzy PID control structure diagram

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 [3-4] 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.[5] 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 has the ability to enforce the optimal performance of the PID in the control loop of the nonlinear time varying systems[6].

3. System model analysis

3.1 Fuzzy PID controller model of random time delay 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 [7]. 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 Fig.2.
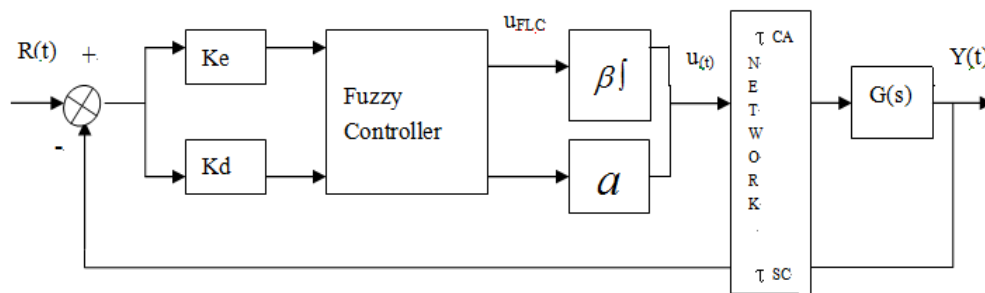

Fig.2 Fuzzy PID control diagram of random time delay network

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.[8]，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 (˙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

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

$$u(t) = \alpha u_{FLC} + \beta \int_0^t u_{FLC}(t)dt \qquad (3)$$

$$u(t) = \alpha(A + PK_e e + DKd\dot{e}) + \beta \int_0^t (A + PK_e e + DKd\dot{e})dt \qquad (4)$$

4. optimization based on genetic algorithm

4.1 the optimizing of fuzzy PID controller base on genetic algorithm

PID based on Genetic algorithm networks controller with delay has many advanced properties compared with traditional PID. Genetic algorithm is based on natural selection and genetic inheritance, which is the method of finding the global optimal direction in the problem solving space [9].Genetic algorithm is the method of biological evolution, 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, the mutation is to prevent the loss of important genetic information. Crossover refers to information exchange between solution vectors based on probabilistic decisions. in each iteration, to give rise to a better method of solution vectors in the next iteration. 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 Optimization of the objective function for time domain performance

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) [10] . 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

$$J = \int_0^\infty [w_1 te(t) + w_2 u^2(t)]dt \qquad (5)$$

4.3 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.

5 Simulation results

The closed loop system with random time delay, its transfer function $T(s) = \dfrac{(s+3)e^{-0.1s}}{(s+1)(4s+1)}$

The system input is a unit step function, the output value of the network delay system is observed by the PID controller，the fuzzy PID controller and the genetic algorithm optimized by the PID controller. 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	the objective function J_{min}	Ke	Kd	a	b
$T(s) = \dfrac{(s+2)e^{-0.1s}}{(s+1)(4s+1)}$	14.52	0.85	0.53	3.08	0.77

Table 2 On-line setting value with delay

transfer function	the objective function Jmin	Ke	Kd	a	b
$T(s) = \dfrac{(s+2)e^{-0.1s}}{(s+1)(4s+1)}$	14.92	1.93	1.08	1.92	0.73

The corresponding output of the Simlink is shown in Figure 3.
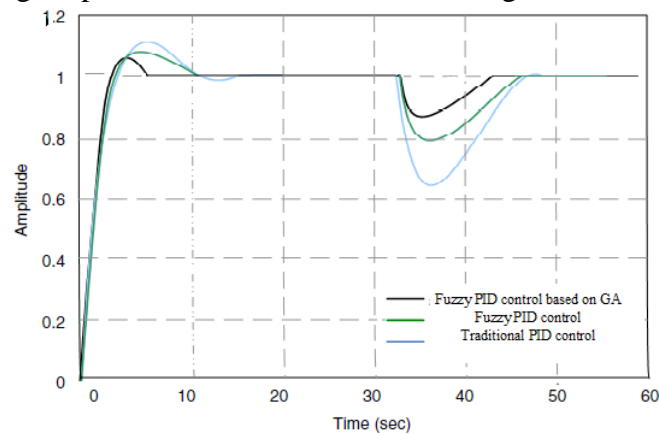

Fig.3 Step response simulation of random delay network unit

5. 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 is superior to the traditional PID control algorithm and 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.

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