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Fuzzy Dynamic Scheduling of Multi-loop NCS

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Abstract

There are more problems of network data transmission in multi-loop NCS than in single loop NCS. It maybe lead to that one or more of closed-loop systems become unstable in multi-loop NCS. In order to solve this problem, a novel algorithm of fuzzy dynamic scheduling for multi-loop NCS is put forward in this paper. Firstly, the requirement of the sampling period of NCS is discussed. The necessity of dynamic scheduling for multi-loop NCS is analyzed. And then, the algorithm of fuzzy dynamic scheduling for multi-loop NCS is proposed. The idea is described form three parts.The principle of fuzzy dynamic scheduling is analyzed. The fuzzy controller is designed. The fuzzy dynamic scheduler is constructed. Finally, the simulation model of a multi-loop NCS with fuzzy dynamic scheduler is set up using TrueTime software. The relevant analysis of simulation is given. The result of study can prove that the performance of each closed control loop based on the same network platform is improved by adding fuzzy dynamic scheduler in the multi-loop NCS.

Keywords: *multi-loop NCS, fuzzy control, dynamic scheduling, the sampling period, priority*

1. Introduction

Compared with traditional control system with point to point control mode, NCS (Networked Control System) has advantages of less wiring, resource sharing, and convenient of fault diagnosis and maintenance. On the other hand, there are some questions maybe emerge and need to be solved, such as delay of network transmission, sequence error of transmitting data packet, packet loss, etc. All this questions have bad influence on the performance of NCS. The performance of NCS depends on not only the control strategies but also scheduling strategies of network. So it is necessary to design a reasonable network scheduling algorithm to optimize the performance of overall NCS.

The current researches on network scheduling mostly focus on the application layer of network. They mainly draw from the task scheduling algorithms of CPU, such as the typical FP (Fix Priority), the RM (Rate Monotonic) [2], the EDF (Earliest Deadline First) [3], etc. FP and RM scheduling algorithms belong to the static scheduling method, which the flexibility of scheduling process is poor. Even EDF is dynamic scheduling, which distributes dynamic the priority according to time deadline of each control loop, its performance of adaptive is poor. Besides scheduling algorithms above, some scholars propose dynamic scheduling algorithm based on "dead zone" [4], static scheduling algorithm based on "time window" [5], and dynamic scheduling algorithm of MEF-TOD (Maximum Error First – Try Once Discard) [6].

Based on the original EDF scheduling algorithm, we put forward fuzzy dynamic scheduling algorithm for multi-loop NCS to reduce the bad influence of network conflict and improve the performance of NCS.

This paper is organized into 6 sections including this section. Section 2 analyzes the influence of the sampling period on performance of NCS. Section 3 discusses the necessity of dynamic schedule for multi-loop NCS. The fuzzy dynamic scheduling algorithm of multi-loop NCS is proposed in section 4. It includes several parts: analyzing the principle of fuzzy dynamic scheduling; giving the design of fuzzy controller; constructing the fuzzy dynamic scheduler. Simulation and analysis are done in section 5. Finally, conclusions are presented.

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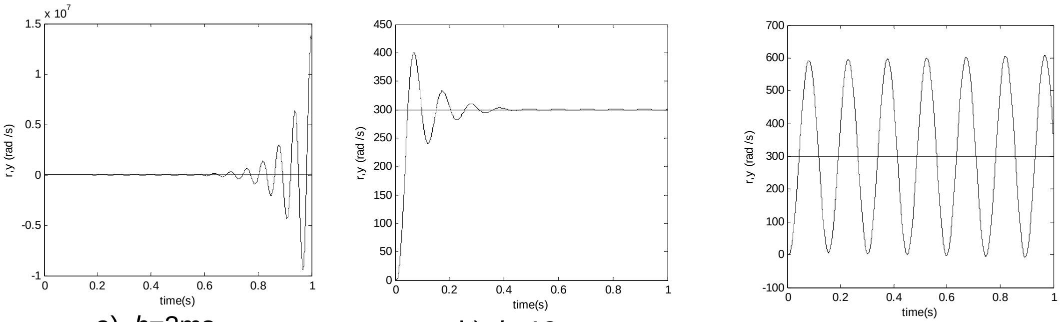
2. The Influence of Sampling Period on the Performance of NCS

In general control system with continuous signals, the feedback error signal received by the controller is continuous. So the sampling period does not affect the effect of control. But in the control system with discrete digital signal, sampling period determines the time interval of feedback signal to controller [7]. NCS is a special kind of digital control system. Its controller receives periodically the feedback signal sampled by sensors.

Although network source are shared by multiple tasks, network permits itself to be occupied by a task in some specified time. In this case, not only the sampling period of feedback signal but also the time interval of the network transmission for feedback signal will influence on the performance of the closed loop control system. As a result, sampling period which is set too long or too short may lead to the output of NCS divergence. For example, we set up a simulation model of a single loop NCS only includes only one controlled plants, one controller node, one sensor node and one actuator node using TrueTime software[8]. Fixed sampling period is usually set for single loop NCS, in which multiple tasks of nodes run according to time division multiplexing model to transmit data through network.

By adjusting the sampling period of NCS, we can get some curves as shown in Figure 1. *h* presents the sampling period of NCS. Figure 1 a) shows the response output when the value of the sampling period of NCS is set too small. Figure 1 c) shows the response output when the value of the sampling period of NCS is set too big. These curves prove that it is very important for NCS to adopt a proper sampling period within a range to ensure a good performance of control system.



a) *h*=3ms b) *h*=12ms c) *h*=28ms

Figure 1. Response output curves using different sampling periods

The multi-loop NCS are used widely which includes several closed loop control system based on the same network platform, such as Figure 2. Each closed loop control system owns itself controlled plant, controller, sensor and actuator.

The choice of the sampling period is more important for multi-loop NCS than single loop NCS. Multi-loop NCS have some features as follow:

1) Different closed loop NCS on same network platform has itself different proper range of sampling period. The response output of NCS will diverge if sampling period beyond the range.

2) Because of different closed loop NCS on same network platform, phenomenon of conflict of data transmission maybe happens. It leads to that multi-loop NCS can not to be scheduled if sampling period of each closed loop NCS is set unsuitable.

3) Even sampling period of each closed loop NCS is set suitable, schedule is still necessary for different closed loop NCS on same network platform to ensure and improve the performance of each closed loop NCS.

3. The Necessity of NCS Dynamic Scheduling

Based on system structure shown of three closed loops NCS in Figure 2, a simulation model of a multi-loop NCS is built using TureTime software. It is shown as Figure 3.

The multi-loop NCS includes three control loops. Each control loop is a closed loop control system which includes sensor, controller, actuator and plant. Each control loop independent carry out their tasks. But they share same network to transmit their data. In Figure 3, each model of network nodes adopts TrueTime toolbox of TrueTime Kernel module. EDF scheduling algorithm is used for TrueTime Network module.

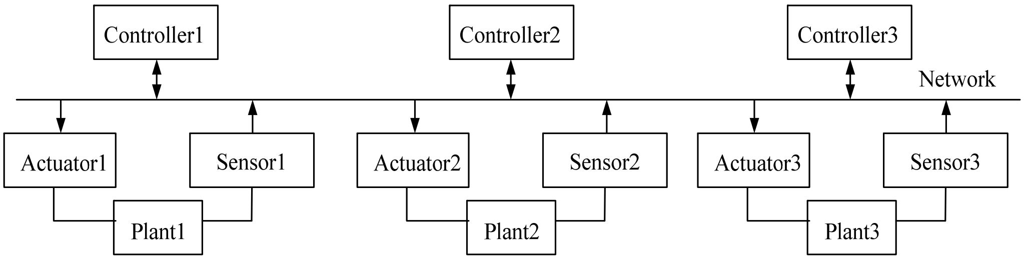


Figure 2. System structure of three closed loops NCS

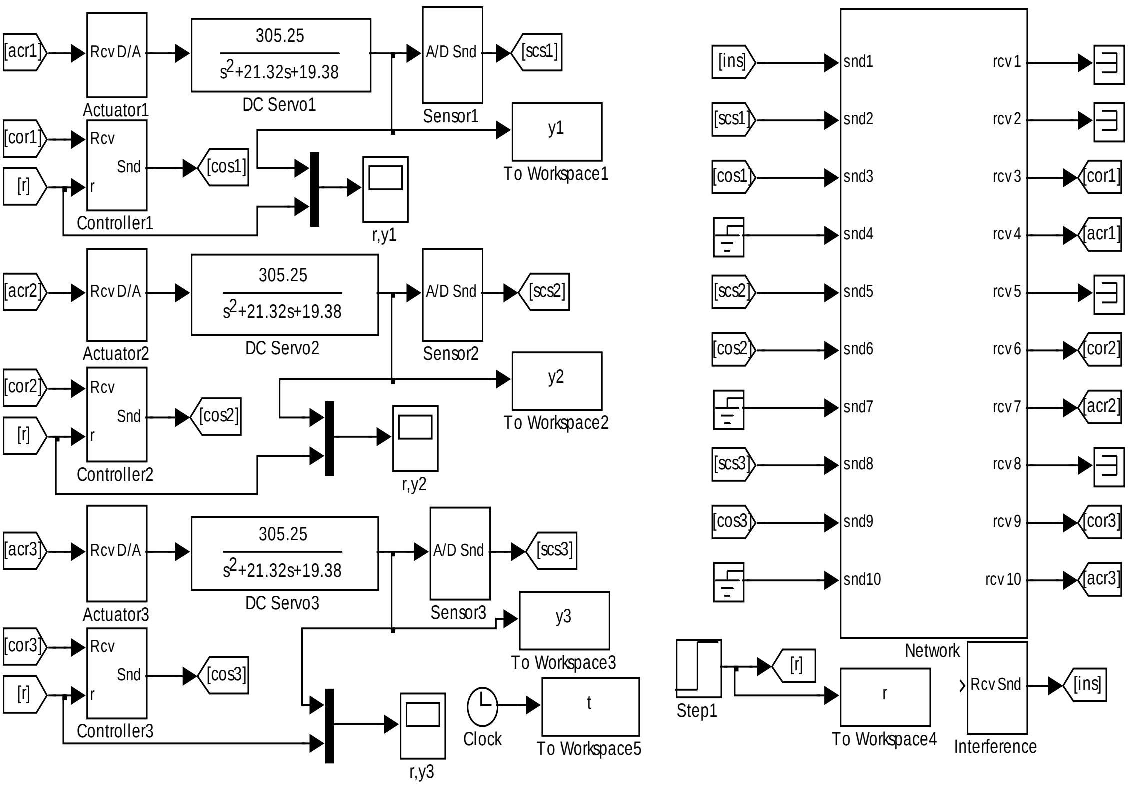
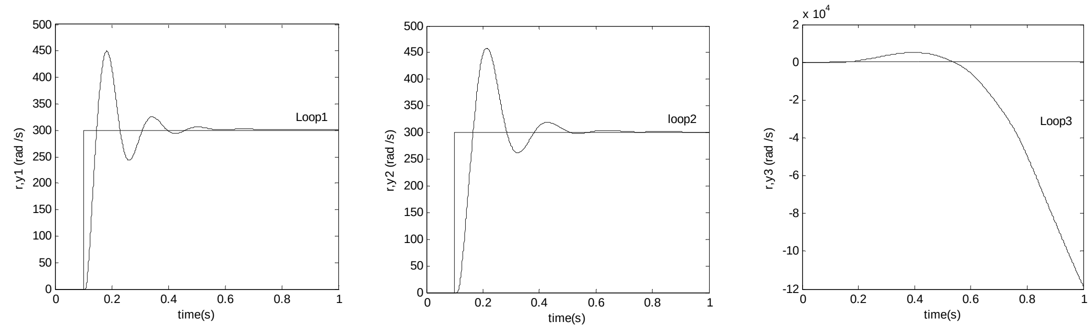


Figure 3. The simulation model of a multi-loop NCS without scheduler

Figure 4 shows response output curves of three control loops system, in which y_1, y_2 and y_3 respectively is response outputs of the 1st control loop, the 2nd control loop and the 3rd control loop. *h* represents the sampling period of each closed loop NCS. The three PID controllers adopt the same parameters: the proportional coefficient K_P is 4.2; K_I integral coefficient is 8 and differential coefficient K_D is 0.02. In this simulation, the other parameters are: network type is 'Round Robin'; the rate of network transmission is 80kbit/s; the sampling period of three control loop respectively is T_1=4ms, T_2=5ms, T_3=6ms.



a) *h*=4ms b) *h*=5ms c) *h*=6ms

Figure 4. Response output curves of three loops without scheduler

The output of the 1st control loop and the 2nd control loop can quickly reach their desired value. It means they transmit data through network in time according to the respective sampling cycle. But the 3rd control loop has to take a long time waiting for data transmission. It leads that the feedback signal can not go back controller in time. The controller can not finish calculating and adjusting the controlled plant. The response output of the 3rd control loop fails to reach the expected value finally. This simulation proves that it necessary for multi-loop NCS to add a scheduler.

4. Fuzzy Dynamic Scheduling Algorithm of Multi-loop NCS

At present, the research on information scheduling of NCS is mostly scheduling of open loop. Based on theory of feedback control, considering the sampling period’s influence on system performance, this paper puts forward a multi-loop fuzzy dynamic scheduling algorithms, which including calculating priority, determining the priority and scheduling tasks of network nodes.

4.1. Principle of Fuzzy Dynamic Scheduling

Principle of fuzzy dynamic scheduling is dynamic distribute the priority of each loop according to response error of each loop in multi-loop NCS. Considering rate of error, two-dimensional fuzzy controller is used to determine the parameter of priority. Figure 5 shows schematic of fuzzy dynamical scheduling algorithm. According to differences $e_1 \dots e_n$ of inputs $r_1 \dots r_n$ with outputs $y_1 \dots y_n$ and rates of difference $ec_1 \dots ec_n$, the priorities of each loop $p_1 \dots p_n$ are obtained by fuzzy inference [9]. The sampling nodes of NCS are usually driven by clock. Once scheduler is used, the nodes of NCS transmit their data or receive their data through network according to arrangement of scheduler.

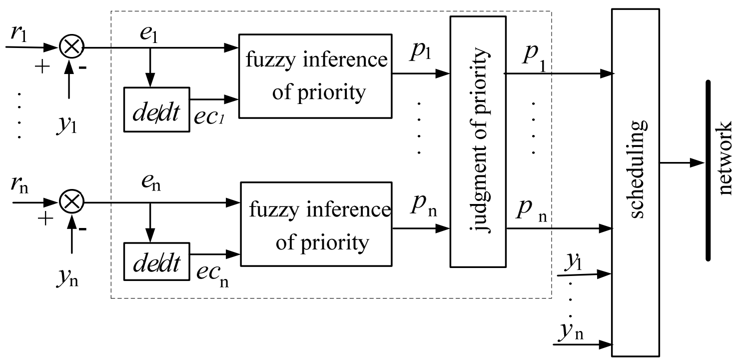


Figure 5. Schematic diagram of fuzzy dynamical scheduling algorithm

The core of this scheduling algorithm is to apply fuzzy control method to determine the priority of control loop in multi-loop NCS. After priority is determined, the scheduler decides the order of adjusting different loops according to the priority of control loop. And the control loop with the highest priority firstly possesses priority of network data transmission to finish its task.

4.2. Design of Fuzzy Controller

The algorithm of fuzzy dynamic scheduling focuses on the distribution of priority of each NCS control loop [10]. Figure 6 is schematic diagram of fuzzy inference of priority. In loop of multi-loop NCS r_i is reference input; y_i is a feedback signal of outputs; e_i is the difference of reference input with output feedback of loop; ec_i is rate of error, $ec_i(k)= e_i(k)- e_i(k-1)$; p_i is the priority of loop. The inputs of fuzzy controller are e_i and ec_i. The output of fuzzy controller is p_i. It is assumed that actual input range of e_i and ec_i is [-1, 1], and actual output range of p_i is [1, 5]. The ratio factor K_e and K_{ec} both equal 4. The quantitative factor K_q equal 1. After fuzzification, e_i and ec_i is respectively translated into E_i and EC_i.

The fuzzy discourse domains are defined as follow:

E_i: {-4, -3, -2, -1, 0, 1, 2, 3, 4}

EC_i: {-4, -3, -2, -1, 0, 1, 2, 3, 4}

P_i: {1, 2, 3, 4, 5}

and fuzzy sets are assigned as follow:

E_i: { NB, NS, ZE, PS, PB}

EC_i: { NB, NS, ZE, PS, PB}

P_i: {PS, S, M, B, PB}

NB represents negative big; NS represents negative small; ZE represents zero; PS represents positive small; PB represents positive big; S represents small; M represents middle; B represents big. The membership function of triangular type is used for *E* and *EC*. The membership function of Gauss type is used for membership *P*.

Fuzzy rules are determined based on the analysis to the relationship of performance of control system with its priority of task. The principle of setting fuzzy control rules is that the output of fuzzy controller can truly reflect the state of loop task in order to rational allocate priority of each control loop in multi-loop NCS [11]. Note that the bigger the value of priority is, the lower the priority of control loop is. In other word, the smaller the value of priority is, the higher the priority of control loop is. Fuzzy set PB corresponds to a low priority, and PS corresponds to a high priority. Table 1 shows the rules of fuzzy control to priority of each control loop in multi-loop NCS.

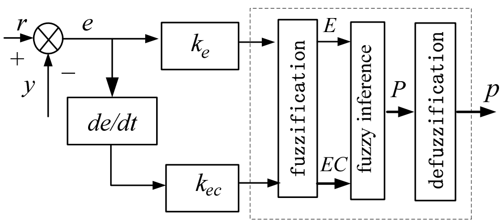


Figure 6. Schematic diagram of fuzzy inference of priority

Table 1. Rules of fuzzy control

P_i		EC_i NB	NS	ZE	PS	PB
E_i	NB	PS	PS	B	S	PS
	NS	PS	S	M	B	PS
	ZE	PS	M	PB	M	PS
	PS	PS	B	M	S	PS
	PB	PS	S	S	PS	PS

By the fuzzy inference and defuzzification using center of gravity method, the true value of the output finally p_i can be got. Equation (1) is the formula of center of gravity method.

$$p = \sum_{k=1}^{5} p_k \mu\left(p_k\right) / \sum_{k=1}^{5} \mu\left(p_k\right) \quad (1)$$

According to the priority calculated out of control loop, NCS will execute task of control loop in sequence according to priority level of each loop, and realize the dynamic scheduling of multi-loop NCS. Because fuzzy dynamic scheduling considers error and error ratio of each control loop, the control loop which performance deviates from set point worst is adjusted in time. So this kind of dynamic scheduling is helpful to improve the whole performance of NCS.

4.3. Design of Fuzzy Dynamic Scheduler

Based on the multi-loop NCS model as shown in Figure 3, the fuzzy scheduler is added into this simulation NCS model. Once the scheduler is added, the sensor sends data to the network according to scheduling of fuzzy scheduler instead of directly transmitting data to the controller through the network. Fuzzy scheduling of multi-loops is used to avoid conflict of data transmission of different control loop. Figure 7 shows the simulation structure diagram of multi-loop fuzzy scheduling. The output signal of three control loop y_1, y_2, and y_3 are respectively connected to the input ports of fuzzy scheduler. And the outputs of fuzzy controller p_1, p_2 and p_3 are also respectively connected to the input ports of the fuzzy scheduler. The other part of dynamic scheduling simulation model of multi-loop NCS is same as Figure 3.

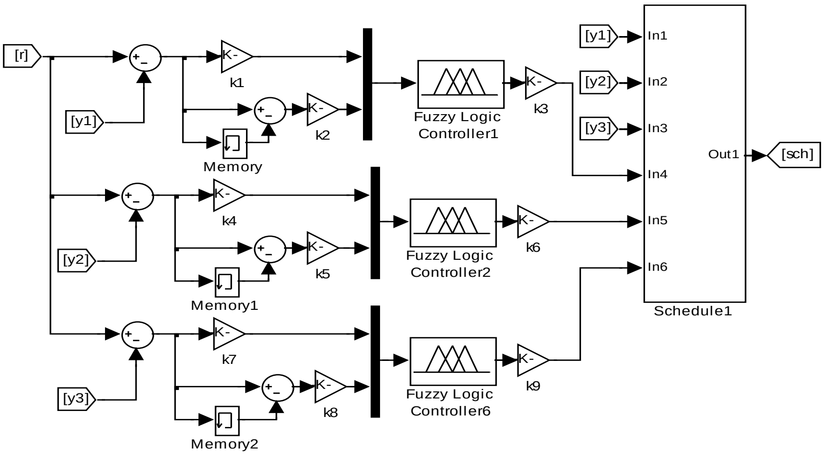


Figure 7. The simulation structure diagram of multi-loop fuzzy scheduling

In Figure 7, the module of scheduler is built using TrueTime Kernel module. By double clicking this module of scheduler within Matlab/simulink, the internal structure of scheduler is shown as Figure 8. Program of scheduler must be written in form of M type file into scheduler_init file. Data of each control loop can be transmitted through network according to the command from scheduler_init file.

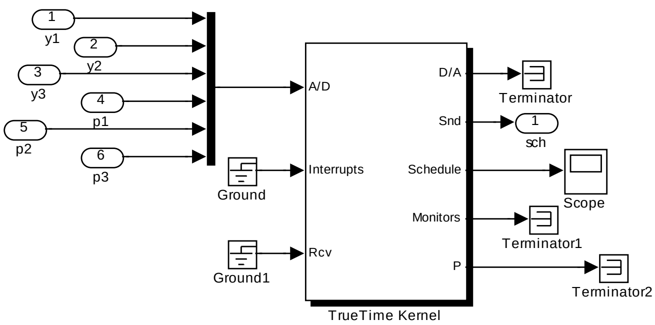
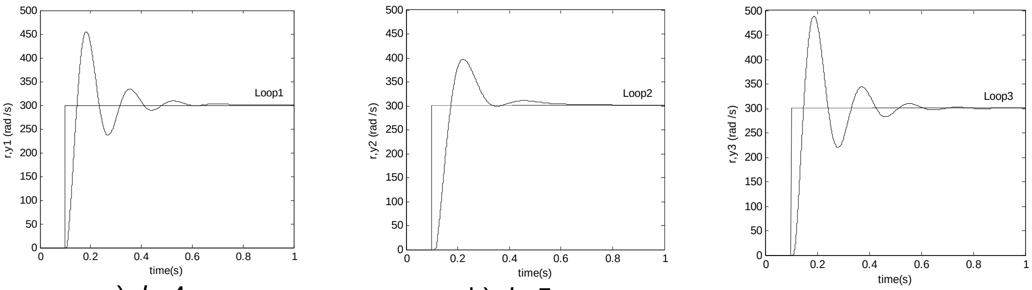


Figure 8. The internal structure of scheduler

5. Fuzzy Dynamic Scheduling Algorithm of Multi-loop NCS

By building simulation model of multi-loop NCS with fuzzy dynamic scheduler, system response curves of three control loop can be got as shown Figure 9. In this simulation, same PID controller and same model of controlled object with same transfer function are adopted in different control loops. And type of network is selected as Round Robin. The other parameters are: network transmission rate is 500kbit/s, the sampling periods of three control loops are T_1=4ms, T_2=5ms and T_3=7ms. The time interval adjusting the priority of fuzzy dynamic scheduler is T_p=50ms. *h* represents the sampling period of each closed loop NCS.

Comparing with Figure 4, we can learn that all the outputs of three control loops can converge to their desired value in Figure 9. The 3rd loop no longer happens divergent phenomenon. This is because fuzzy scheduler reasonable arrangement sequence of data transmission of different controller. The overall performance of NCS was improved obviously.



a) *h*=4ms b) *h*=5ms c) *h*=7ms

Figure 9. Response output curves of three loops with fuzzy scheduler

From the 'schedule' output of TrueTime Kernel in Figure 8, we can observe the time sequence diagram of NCS network node running. It includes three statuses: no data transmission, waiting data transmission and sending data.

When scheduler isn't used in Figure 4, the 1st control loop and the 2nd control loop are usually stay two statuses: no data transmission or sending data. But the 3rd control loop always stay waiting data transmission because of network conflict. It eventually leads that the response output of the 3rd control loop is divergent.

After scheduler is used in Figure 9, data transmission of network nodes of three control loops is reasonably arranged by the fuzzy dynamic scheduler. They all usually stay two statuses: no data transmission or sending data in time. This process greatly improves the performance of each control loop of NCS.

6. Conclusion

Summarizing the work above, some conclusions are given as follow:

1) An important premise of implementing dynamic network scheduling in a multi-loop NCS is that the sampling period of each closed control loop in multi-loop NCS should be in a certain range which is neither too big nor too small.

2) The idea of fuzzy dynamic scheduling is to calculate priority of each closed control loop according to their error and rate of error network parameters, and to execute scheduling according to the value of priority. This idea make those control loop which output deviates heavily from the expected value possesses priority of network transmission, and be regulated as soon as possible. It ensures that each closed control loop can satisfy with the requirements of steady and dynamic performance.

3) The result of simulation proves that the performance of each closed loop control system based on same network platform is improved effectively by adding fuzzy dynamic scheduler in multi-loop NCS.

Acknowledgement

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