Study of NCS with Improvement Smith Predictor and Fuzzy Immune Control

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Abstract

Network induced delay is the main factor that deteriorates the performance of networked control. In order to effectively restrain the impact of network delay on NCS, a new approach is proposed that improved Smith dynamic predictor combines fuzzy immune PID control. Because this dynamic Smith predictor does not include network induced delay models, therefore it is applicable to some occasions that network induced delays are time-variant, uncertain, and larger than one sampling period, even tens of sampling periods, simulation results show that the approach is effective.

Keywords: Networked control system (NCS), Network induced delay, Smith predictor, fuzzy immune control

1. Introduction

Sensor, controller and actuator are sequentially connected via dedicated wiring, such control system, whose feedback loop is closed via a network, is called Networked Control System (NCS)[1]. Although using network provides many benefits such as less wiring, better interfacing, lower costs, simple installation and maintenance, high reliability and an open architecture. However there are some disadvantages such as communication delays, non-delivery of the message carrying the loop information from one component to the other.

In the NCS, one of the important issues to treat is the effect of the network induced delay on the system performance, It is well-known that time delay in a closed loop control system degrades the performance and can lead to system instability [2, 3].

In order to overcome influences of time-delay for NCS performance, according to variety property of time-delay , the primary approaches of controlling the plant with network induced delays are certainty control in [4,5] and stochastic control in [6,7]. The literature [8] changes time-varying system into time invariance system through the introduction of buffer, this method solves the case that the control delay is larger than one sampling period, the disadvantage is that the insertion of buffer artificially expands all the delays, and thus the system performance is reduced. Kim et al [9] propose a new method for obtaining a maximum allowable delay bound for the scheduling of the NCS. Liu et al [10,11] study the design, simulation and implementation of networked predictive control system, it is simulated in the off-line and real-time simulation environment and also implemented in a networked predictive servo-control test rig. It is shown that predictive control is an active network delay compensation method. Chen et al [12] study Smith predictor in the NCS based on delay identification. Fite et al [13] propose the use of a Smith predictor in the architecture of the bilateral manipulation system to compensate for the destabilizing effects due to the presence of time delay, includes a model adaptation scheme in the predictor, to realize certain robustness of adapting dynamics environment.

The defects of above methods are to require controller or actuator storing a large amount of past information [14], or suppose the network induced delay is constant, or distribution is known, or sensor-to-controller delay τsc is equal to controller-to-actuator delay τsc, or the network induced delay is shorter than one sampling period, or the network induced delay through the introduction of buffer is larger than one sampling period, or need on-line measure or identification network induced delay. However, because of clock asynchronous of network nodes [15], or delay uncertainty, it is difficult for description delay by means of accurate mathematical models. Based on Smith prediction compensator principle [16], if the prediction model can accurately approximate the true model, network induced delays should be completely eliminated from closed loop characteristic equation. Otherwise, the performances of control system will degrade, even system destabilization.

In this paper, a new improved Smith dynamic prediction compensation approach is proposed. It realizes double Smith dynamic prediction compensations to network induced delays and true plant time delay. Furthermore, we can totally eliminate the delay τsc in the return path, while removing the delays τca and τp in the forward path from the loop, where delays are allowed to be time-variant, uncertain, and possibly large compared to one sampling period, even tens sampling periods. Therefore, the traffic on the return path does not need to be scheduled, allows utilizing the capacity of the communication channel more effectively than static or dynamic scheduling could. In order to increase the systematic robustness and the ability of interference rejection, controller adopts fuzzy immune self regulating PID control, and simulation results show that the approach is effective.

This paper is organized for four Sections as follows: Section 2 analyzes the Smith predictor and proposes a new improvement Smith dynamic prediction compensator approach, introduces fuzzy immune self regulating PID control strategy. The simulation is described in Section 3, followed by conclusions in Section 4.

2. Problem description

In the NCS, the network induced delay is primary factor which influences on the system performance. Under different scheduling protocol, the network induced delay may be constant, time-varying, or even random variable [I7], the typical structure of NCS is shown as figure 1:

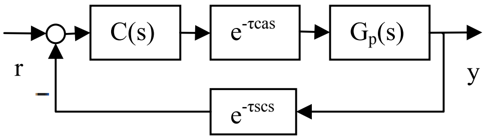


Fig.1: Structure of NCS.

We assume that sensor is time-driven, controller and actuator are event-driven, and total delay is greater than one sampling period, even tens sampling periods. Where $G_p(s)$ is the controlled plant without time delay, C(s) is the controller, r and y are the input and output of the system respectively, τsc and τca are network induced delays, τsc from sensor to controller, and τca from controller to actuator.

The closed loop transfer function of the system is given by

$$y(s) / r(s) = C(s)e^{-\tau cas}G_p(s)/(1+C(s)e^{-\tau cas}G_p(s)e^{-\tau scs}) \quad (1)$$

From formula (1) can be seen that e and e have been contained in the denominator of the closed loop transfer function, they will degrade the stability of NCS.

2.1. Smith predictor of the NCS

The internal compensation loop is closed around the controlled plant side of the network. Smith predictor based on controlled plant can be described as Fig.2.

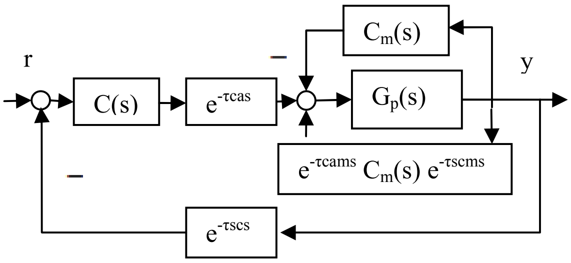


Fig. 2: NCS with Smith predictor in controlled plant.

Where $C_m(s)$ is prediction model of the controller C(s), τscm is prediction value of network induced delay τsc, and τcam is prediction value of network induced delay τca. The closed loop transfer function of the system as follows:

$$y(s) / r(s) = C(s)e^{-\tau cas}G_p(s) / (1 + C(s)e^{-\tau cas}G_p(s)e^{-\tau scs} - G_p(s)e^{-\tau scms}C_m(s)e^{-\tau cams} + G_p(s)C_m(s)) \quad (2)$$

If τcam = τca, τscm = τsc, $C_m(s)$ = C(s), the prediction models can accurately approximate the true models, the above equation (2) is reduced to

$$y(s) / r(s) = C(s)e^{-\tau cas}G_p(s) / (1 + G_p(s)C(s)) \quad (3)$$

As can be seen from (3), the effects of the delays have been completely eliminated from the denominator of the transfer function. The system of fig.2 can is simplified as fig.3.

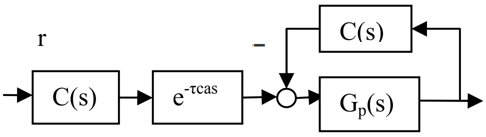


Fig. 3: Equivalent control system.

If the controller C(s) in the forward path is commutative with time-variant delay $e^{-\tau cas}$, then the system of fig.3 can is treated as the system of fig.4.

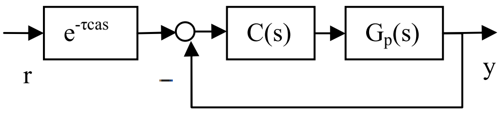


Fig. 4: Equivalent system if C(s) and $e^{-\tau cas}$ are commutative.

In despite of Smith prediction compensator can totally eliminate the delay τsc in the return path, while removing the delay τca in the forward path from the loop, thus scheduling in the return path is not needed. When the prediction models can accurately approximate the true models ($\tau cam = \tau ca$, $\tau scm = \tau sc$, $C_m(s) = C(s)$), the delays can be totally compensated. But above-mentioned Smith predictor has some problems:

- In practical NCS, the complete compensation conditions of Smith predictor are difficultly meet. First, because of delay uncertainty, it is hard to get the precise prediction models which include the network induced delay τsc and τca. Secondly, on account of the clock asynchronous of network nodes, it is difficult to get the exact values of τsc and τca by means of on-line measurement or identification. Thirdly, owing to delay results in vacancy sampling and mult-sampling, Smith predictor will bring compensation model errors.
- When delay large compared to one sampling period, even tens sampling periods, a lot of memory units are required for storing old data in controller and actuator, consume memory resources and increase calculation delay inside nodes.
- When controlled plant includes delay τp, in formula (3), the denominator of the transfer function will contains exponent $e^{-\tau ps}$, the stability of NCS should be influence.

2.2. Improved Smith predictor

We aim at existent issues in fig. 2, if $C_m(s) = C(s)$, an improved Smith dynamic predictor is shown in Fig. 5.

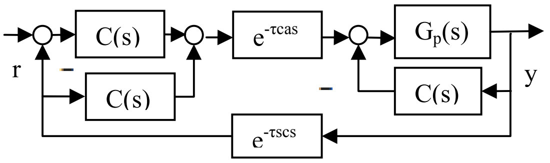


Fig. 5: NCS with improved Smith predictor.

If the controller C(s) in the forward path is commutative with time-variant delay $e^{-\tau cas}$, then the system of fig.5 can is treated as the system of fig.6.

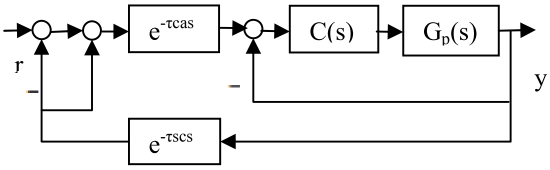


Fig. 6: Equivalent control system.

When transfer function of true controlled plant is $G_p(s)e^{-\tau ps}$, prediction model is $G_{pm}(s)e^{-\tau pms}$, in order to eliminate influences of delay $e^{-\tau ps}$, by means of Smith prediction compensation principle, the system of fig.6 can is simplified as fig.7.

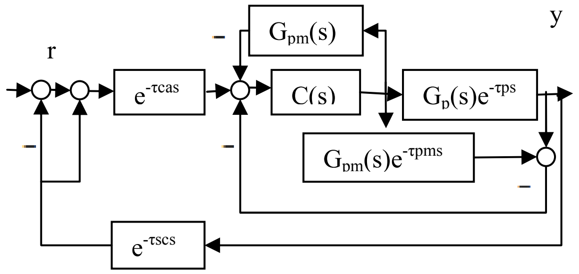


Fig. 7: Double Smith predictor if plant is $G_p(s)e^{-\tau ps}$.

The closed loop transfer function of the system as follows:

$$y(s)\,/\,r(s) = e^{-\tau cas}C(s)G_p(s)e^{-\tau ps}/(1 + C(s)G_{pm}(s) + C(s)(\,G_p(s)e^{-\tau ps} - G_{pm}(s)e^{-\tau pms}\,)) \qquad (4)$$

If $\tau pm = \tau p$, $G_{pm}(s) = G_p(s)$, the prediction models can accurately approximate true models, the above equation (4) is reduced to

$$y(s)\,/\,r(s) = e^{-\tau cas}C(s)G_p(s)e^{-\tau ps}/(1 + C(s)G_p(s)) \qquad (5)$$

Then the system of fig.7 can is treated as the system of fig.8.

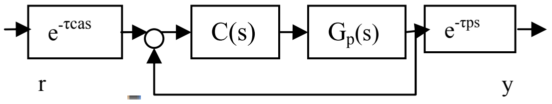


Fig.8: Equivalent control system.

According to Fig. 5 to Fig. 8, we can see

- The improved Smith dynamic prediction compensator can cancel effects the delays which include network induced delay τsc , τca and controlled plant delay τp in the closed loop system, it realizes double Smith dynamic prediction compensations.

- In improved predictor, there are no network induced delay prediction models of τscm and τcam, network induced delays do not need to be measured and identified of on-line, therefore network induced delays are allowed to be time-variant, uncertain, and possibly large compared to one sampling period, even tens sampling periods. If only $G_{pm}(s) = G_p(s)$, $\tau pm = \tau p$, Smith dynamic predictor is always effective.
- C(s) controller can adopt traditional PID, also adopts intelligent control strategy. In order to increase the system robustness and the ability

of interference rejection, controller adopts fuzzy immune self regulating PID control.

2.3. Fuzzy immune PID control

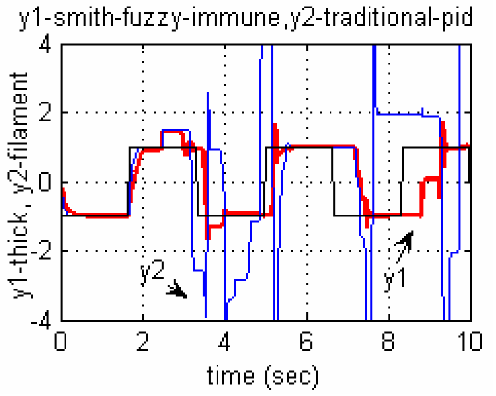
As is known, immune is a special physiological reaction in biosome, corresponding antibody is produced to resist attacking antigen, which is destroyed by phagocytosis or particular enzyme generated by antibody. Immune system is composed of antibody and lymphocyte, which is made up of T cells(auxiliary cell T_h and suppressor cell T_s) produced by thymocyte and B cells created by marrow. When antigen invades organism and is digested by surrounding cells, messages are sent to T_h and T_s cells, and B cell is stimulated to create more antibody so as to eliminate antigen. If quantity of antigen is large, much more auxiliary cells T_h yield, but number of suppressor cell T_s reduces, which results in more B cell production; if antigen becomes less, number of T_s increases and that of T_h decreases, which results in the decrease of B cell. Synergism between suppressor mechanism and main feedback mechanism is realized through quick response of immune system to antigen and stabilizing immune system.

Based on the immune feedback theory, we adopt fuzzy immune self regulating PID control strategy [18].

3. Simulation experiment

We use improved Smith predictor, simulation software selects Truetime 1.5 [19], simulation network choose CSMA/CD(Ethernet), sampling period h= 0.01 second, given signal adopts square wave. The network induced delays are allowed to be time-variant, uncertain and possibly large compared to one sampling period, even tens sampling periods.

In order to compare control effects under the same network conditions, two selfsame controlled plants of plant1 and plant2 are selected, their inputs are u1 and u2, outputs are y1 and y2, respectively, and all data are encapsulated in the same data package for network transmission together. The plant1 is controlled by improved Smith predictor plus fuzzy immune self regulating PID control strategy, and the plant2 is controlled by traditional PID control strategy. Simulation controlled plant is first-order plus delay system as follows:



$$G_p(s)e^{-\tau_p s} = 100e^{-0.02s} / (s + 100) \qquad (6)$$

In simulation process, a step disturbance signal, which amplitude is 0.5, is inserted at 2.5 second, the simulation results are shown in fig.9 to fig.12.

Fig. 10: Network schedule.

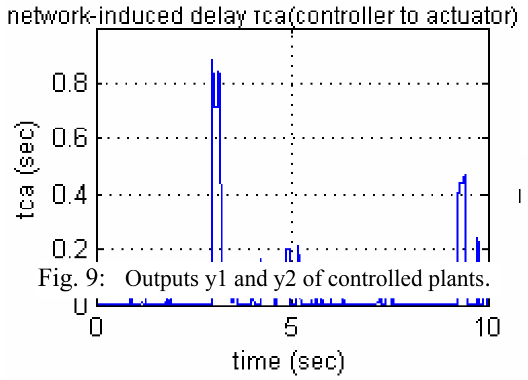


Fig. 9: Outputs y1 and y2 of controlled plants.

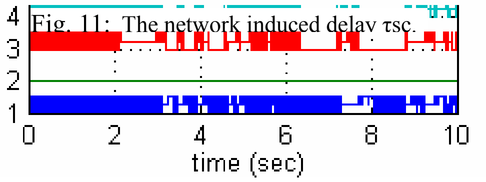


Fig. 11: The network induced delay τsc.

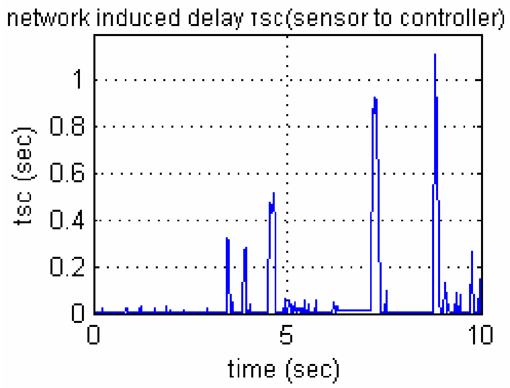


Fig. 12: The network induced delay τca.

From fig.9 to fig.12, we can see that the τsc and τca of network included delay are random, time variant and uncertain, the τsc maximum is 1.12 second and τca maximum is 0.88 second(sampling period h is 0.01 second). The y1 (in fig.9, thick line expression) satisfies the performance requirements of the NCS. However, because y2 (in fig.9, filament expression) at 3.6 second, 4.0 second, 5.2 second, 7.4 second and

9.32 second surges and transpires, these fluctuates result in system instability, therefore it doesn't satisfy the performance requirements of NCS.

Simulation results show that the new improved Smith dynamic predictor combining fuzzy immune self regulating PID control is effective.

4. Conclusion

In order to overcome influences of network induced delay for NCS performance, a new improved Smith dynamic prediction compensation approach is proposed. Its realization is unconcerned with network induced delays of τsc and τca, whether network induced delays are time-variant, uncertain and possibly large compared to one sampling period, even tens sampling periods. Further, In order to increase the system robustness and the ability of interference rejection, controller adopts fuzzy immune self regulating PID control. Simulation results show that the approach is effective.

Improved Smith dynamic predictor is simple in structure, based on intelligent nodes [20], it is easy for actualization, therefore it has widely application prospect.

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