

Study on integrated scheduling method of networked cascade control system with double-sampling rate

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Abstract: For network cascade control system with double-sampling rate, the paper proposes a new comprehensive scheduling strategy. In the comprehensive scheduling strategy, the variable sampling period algorithm is used in inner-loop and the forecast values are calculated by the cubic exponential differential smoothing method. The dead scheduling approach is used in outer-loop and the dead range adjustment algorithm is analyzed. Finally, an example is presented to test the validity and effectiveness of the comprehensive proposed in this paper.

Introduction

The network control system (NCSs) is characterized that the control information is exchanged through the network [1,2]. If the controlled object is connected via a network which have different sampling rate, it is called multi-rate NCSs. Network cascade control system is a special multi-rate NCSs, which have inner-loop and outer-loop.

Currently, the studies of NCS scheduling have mainly TOD dynamic scheduling [3,5], Variable sampling period scheduling [6,8], Dead scheduling [9,11]. But these methods can't adapt to network cascade control system with double-sampling rate, and its study of scheduling is less, now.

The comprehensive scheduling of network cascade control system is studied in the paper, the variable sampling period scheduling is used in the inner-loop, and the dead scheduling is used in the outer-loop. The simulation proved that the method is effective on network cascade control system with double-sampling rate.

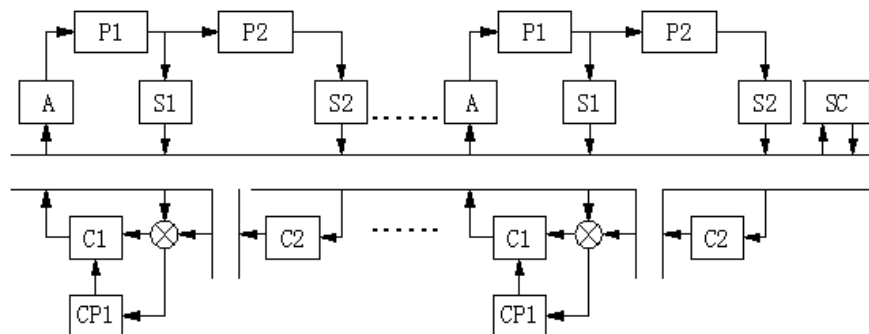


Figure 1 the structure of network cascade control system with double-sampling rate

The comprehensive scheduling program

As shown in figure 1, P1 is the controlled object 1, P2 is the controlled object 2, A is the actuator, S1 is the sensor 1, S2 is the sensor 2, C1 is the controller 1, C2 is the controller 2, CP1 is the dead District compensator, SC is the scheduler. P1, S1, C1, and A is consist of inner-loop, P1, P2, S2, C2, C1, and A is consist of inner-loop.

The system has the following assume: 1) sensors are time-driven, controllers are event-driven. 2) The sampling period of inner-loop T_1 is less than the outer-loop T_2 , and j_1 and j_2 are monitoring cycles about the inner-loop and outer-loop.

Inner-loop scheduling

Network utilization rate and execution time

U_1^i and \hat{U}_1^i is network utilization rate in the actual and predicted; $\dot{U}_1^{i(1)}$, $\dot{U}_1^{i(2)}$ and $\dot{U}_1^{i(3)}$ is respective first order, second order and third order smoothed value, α is the smoothing factor which is the 0.1 to 0.9. The forecasting model of network utilization rate in the inner-loop is

$$\hat{U}_1^i(j_1+1) = E_U + F_U + G_U \quad (1)$$

Which

$$\begin{aligned} E_U &= 3\dot{U}_1^{i(1)}(j_1) - 3\dot{U}_1^{i(2)}(j_1) + \dot{U}_1^{i(3)}(j_1) \\ F_U &= \frac{\alpha}{2(1-\alpha)} \left[(6-5\alpha)\dot{U}_1^{i(1)}(j_1) - 2(5-4\alpha)\dot{U}_1^{i(2)}(j_1) + (4-3\alpha)\dot{U}_1^{i(3)}(j_1) \right] \\ G_U &= \frac{\alpha^2}{2(1-\alpha)^2} \left[\dot{U}_1^{i(1)}(j_1) - 2\dot{U}_1^{i(2)}(j_1) + \dot{U}_1^{i(3)}(j_1) \right] \\ \dot{U}_1^{i(1)}(j_1) &= \alpha \sum_{n=0}^{\infty} (1-\alpha)^n U_1^i(j_1-n) \\ \dot{U}_1^{i(2)}(j_1) &= \alpha \sum_{n=0}^{\infty} (1-\alpha)^n \dot{U}_1^{i(1)}(j_1-n) \\ \dot{U}_1^{i(3)}(j_1) &= \alpha \sum_{n=0}^{\infty} (1-\alpha)^n \dot{U}_1^{i(2)}(j_1-n) \end{aligned}$$

The execution time of forecast is similar to Network utilization rate of forecast.

$$\hat{C}_1^i(j_1+1) = E_C + F_C + G_C \quad (2)$$

The distribution of the inner-loop network utilization rate

At first, the minimum network utilization rate $U_{1\min}^i$ is ensured in inner-loop[6]. The utilization rate in j_1 monitoring period is

$$\bar{U}_1^i(j_1) = U_{1\min}^i(j_1) + q^i \left[\hat{U}(j_1+1) - \sum_{i=1}^n U_{1\min}^i(j_1) \right] \quad (3)$$

Which $U_{1\min}^i(j_1) = \sum_{i=1}^n \hat{C}^i(j_1) / \hat{T}_{\max}^i$, \hat{T}_{\max}^i is the largest sampling period in the inner loop, the demand value of the inner network resources is $q^i = IAE_1^i / \sum_{r=1}^N IAE_1^r$ ($r = 1, \dots, N$).

At the j_2 monitoring period, the inner-loop sampling time have two cases: (1) the outer-loop and inner-loop have different sample time; (2) the inner-loop and outer-loop of sample time is same.

$d^i(j_2)$ is the difference value of inner and outer in the i loop at the j_2 monitoring cycles.

$$d^i(j_2) = [T_1^i(j_2) + \dots + T_1^i(j_2) + d^i(j_2-1)] - T_2^i(j_2) \quad (4)$$

The network utilization of the j_2 monitoring period are:

(1) If $d^i(j_2) \neq 0$, which is satisfied the conditions (1), the inner-loop of the network utilization is

$$\bar{U}_1^i(t) = \bar{U}_1^i(j_1), t = j_1 \text{ or } j_2$$

(2) If $d^i(j_2) = 0$, which is satisfied the conditions (2), the assigned value of inner-loop network

$$\text{utilization is } \bar{U}_1^i(t) = \begin{cases} \bar{U}_1^i(j_1), & t = j_1 \\ U_{1\min}^i(j_2), & t = j_2 \end{cases}$$

Inner-loop sampling period

The sampling period T_1^i of the inner-loop have

$$T_1^i(t) = \hat{C}_1^i(t) / \bar{U}_1^i(t) = \begin{cases} \hat{C}_1^i(j_1) / \bar{U}_1^i(j_1), t = j_1 \\ \hat{C}_1^i(j_2) / \bar{U}_1^i(j_2), t = j_2, d(j_2) \neq 0 \\ \hat{C}_1^i(j_2) / U_{1\min}^i(j_2), t = j_2, d(j_2) = 0 \end{cases} \quad (5)$$

The inner-loop sampling period is bounded and varied, which is $T_1^i \in [T_{1\min}^i, T_{1\max}^i]$, $T_{1\min}^i = C_{1\min}^i / U_{\max}$ and $2D^i / R \leq T_{1\max}^i \leq 2\pi / 10F$. $C_{1\min}^i$ is the execution time of i loop without packet collisions, $C_{1\min}^i = 2L^i / B$; L^i is the length of the packet in the i loop; B is the transfer rate. $U_{1\max}^i$ is the maximum network utilization of the i inner-loop. The minimum throughput of the network is R , the length of the i inner-loop message is D^i , the maximum frequency of the system is F .

Outer-loop scheduling

Dead criterion

The dead scheduling algorithm

$$\Delta y_{p2}^i(j_2) = |y_{p2}^i(j_2) - y_{p2}^i(j_2 - 1)| \leq d^i \quad (6)$$

y_{p2}^i is the output of the sensor 2 in the i -loop. d^i is the dead zone value in the i loop.

At the outer-loop sampling time, sensor 2 determined whether information meets Dead criterion. If it meets Dead criterion, the sensor 2 stops sending signals.

The dead range adjustment algorithm

The dead range adjustment algorithm is used to adjust the value of the dead zone. In [11], the dead value d^i is more than 0.03, the performance of the system is deterioration. M_u^i is the missing rate in the $d^i = 0.03$, M_m^i is the missing rate when the Q_2^i is maximum, M^i is the missing rate in dead value d^i , $M^i = [M_u^i, M_m^i]$

The dead range adjustment algorithm is

$$d^i(j_2) = d^i(j_2 - 1) + \Delta d^i(j_2) \quad (7)$$

Which $\Delta d^i(j_2) = K_p[r(j_2) - r(j_2 - 1)] + K_1 e(j_2) + K_D[r(j_2) - 2r(j_2 - 1) + r(j_2 - 2)]$, K_p , K_1 and K_D is determined by the simulation. The adjustment value $r(j_2)$ is selected as

$$r(j_2) = \begin{cases} M_u^i, M_i(j_2) \in [0, M_u^i] \\ 0, M_i(j_2) \in [M_u^i, M_m^i] \\ M^i, M_i(j_2) \in [M_m^i, +\infty] \end{cases} \quad (8)$$

Simulation

TureTime1.5 is used to simulate the system. Three systems have same parameters.

The controlled object 1

$$A_1 = \begin{bmatrix} -0.2 & -1 & -0.1 \\ 1.2 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} B_1 = [1 \ 0 \ 0]^T C_1 = [0 \ 0 \ 0.135]^T$$

The controlled object 2

$$A_2 = \begin{bmatrix} -0.2 & -0.011 \\ 5 & 0 \end{bmatrix} B_2 = [1 \ 0]^T C_2 = [0 \ 0.011]^T$$

The system have $K_1 = -0.19$, $K_2 = 0.35$. The initial sampling period are $T_1 = 1s$ and $T_2 = 3s$. The maximum sampling period of inner-loop is $T_{1\max} = 10s$, the network bandwidth is 800b/s. the simulation time is 300s. The input is the square wave of 0.008Hz.

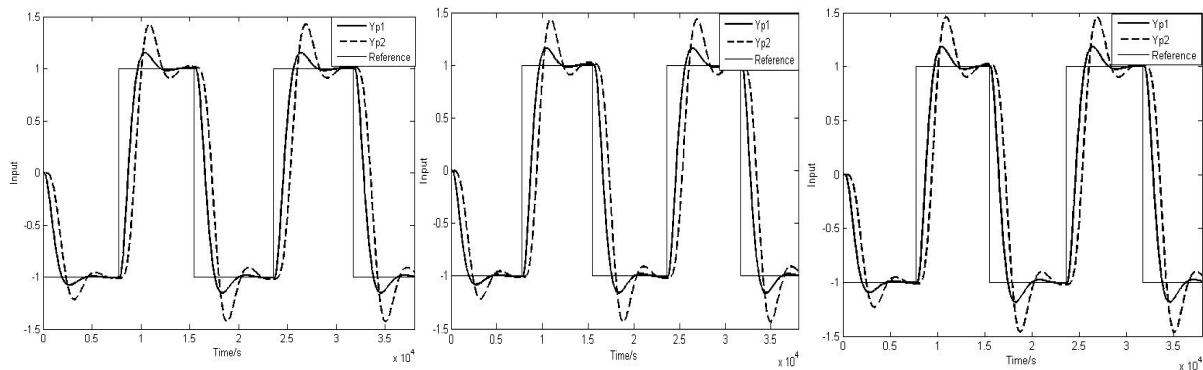


Figure2 the input/output response of loop1/ loop2/ loop3 in the comprehensive strategy

Conclusions

For network cascade control system with double-sampling rate, the comprehensive scheduling strategy is proposed in the paper. The variable sampling period scheduling algorithm is used in the inner-loop, the sampling period is forecasted by the cubic exponential smoothing method. The dead zone scheduling is adopted in outer-loop. The simulation shows that the comprehensive scheduling strategy can regulate multi-loop system to keep the performance.

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