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](image)

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

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

\[
\hat{U}_i^t(j_i+1) = E_U + F_U + G_U
\]

Which

\[
E_U = 3\hat{U}_i^{(1)}(j_i) - 3\hat{U}_i^{(2)}(j_i) + \hat{U}_i^{(3)}(j_i)
\]

\[
F_U = \frac{\alpha}{2(1-\alpha)} \left[ (6-5\alpha)\hat{U}_i^{(1)}(j_i) - 2(5-4\alpha)\hat{U}_i^{(2)}(j_i) + (4-3\alpha)\hat{U}_i^{(3)}(j_i) \right]
\]

\[
G_U = \frac{\alpha^2}{2(1-\alpha)^2} \left[ \hat{U}_i^{(1)}(j_i) - 2\hat{U}_i^{(2)}(j_i) + \hat{U}_i^{(3)}(j_i) \right]
\]

\[
\hat{U}_i^{(1)}(j_i) = \alpha \sum_{n=0}^{\infty} (1-\alpha)^n U_i^t(j_i-n)
\]

\[
\hat{U}_i^{(2)}(j_i) = \alpha \sum_{n=0}^{\infty} (1-\alpha)^n \hat{U}_i^{(1)}(j_i-n)
\]

\[
\hat{U}_i^{(3)}(j_i) = \alpha \sum_{n=0}^{\infty} (1-\alpha)^n \hat{U}_i^{(2)}(j_i-n)
\]

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

\[
\hat{C}_i(j_i+1) = E_C + F_C + G_C
\]

The distribution of the inner-loop network utilization rate

At first, the minimum network utilization rate \(U_{i\min}\) is ensured in inner-loop[6]. The utilization rate in \(j_i\) monitoring period is

\[
\bar{U}_i^t(j_i) = U_{i\min}(j_i) + q^t \left[ \hat{U}(j_i+1) - \sum_{j=1}^{\infty} U_{i\min}(j_i) \right]
\]

Which \(U_{i\min}(j_i) = \sum_{t=1}^{\infty} \hat{C}_i(j_i)/\hat{T}_{i\max}^t\), \(\hat{T}_{i\max}^t\) is the largest sampling period in the inner-loop, the demand value of the inner network resources is \(q^t = IA_E^t / \sum_{r=1}^{N} IA_E^r(r = 1, ..., N)\).

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.

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

\[
d^t(j_2) = [T_i^t(j_2) + ... + T_i^t(j_2) + d^t(j_2-1)] - T_i^t(j_2)
\]

The network utilization of the \(j_2\) monitoring period are:

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

\[
\bar{U}_i^t(j_i) = \bar{U}_i(j_i), t = j_1 \text{ or } j_2
\]

2. If \(d^t(j_2) = 0\), which is satisfied the conditions (2), the assigned value of inner-loop network utilization

\[
\bar{U}_i^t(j_i) = \begin{cases} 
\bar{U}_i(j_i), t = j_2 \\
U_{i\min}(j_2), t = j_3
\end{cases}
\]

Inner-loop sampling period

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

**Outer-loop scheduling**

**Dead criterion**

The dead scheduling algorithm
\[ \Delta y_{p2}^i(j_2) = |y_{p2}^i(j_2) - y_{p2}^i(j_2 - 1)| \leq d^i \] (6)

\( y_{p2}^i \) is the output of the sensor 2 in the loop. \( d^i \) is the dead zone value in the 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. \( M'_{u} \) is the missing rate in \( d^i = 0.03 \), \( M'_m \) is the missing rate when the \( Q^i_2 \) is maximum, \( M' \) is the missing rate in dead value \( d^i \), \( M'[u, M'_m] \)

The dead range adjustment algorithm is
\[ d^i(j_2) = d^i(j_2 - 1) + \Delta d^i(j_2) \] (7)

Which \( \Delta d^i(j_2) = K_p[r(j_2) - r(j_2 - 1)] + K_e(j_2) + K_d[r(j_2) - 2r(j_2 - 1) + r(j_2 - 2)] \), \( K_p \), \( K_e \) and \( K_d \) is determined by the simulation. The adjustment value \( r(j_2) \) is selected as
\[ r(j_2) = \begin{cases} 
M'_u, & M'_i(j_2) \in [0, M'_u] \\
0, & M'_i(j_2) \in [M'_u, M'_m] \\
M', & M'_i(j_2) \in [M'_m, +\infty) 
\end{cases} \] (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 \( T_{i\text{max}}^t = 10s \), the network bandwidth is 800b/s. The simulation time is 300s. The input is the square wave of 0.008Hz.
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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Reference