Design the ADRC for Induced Delay of NCS

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Abstract. Based on researching induced delay longer than sampling time of network control system, major problem is due to network communication system model uncertainty，that leads to poor control performance. Active disturbance rejection control (ADRC) that based on Uncertainty model is used in this paper, network system and control object are regarded as control object together, the network induced delay be as uncertainties in the controlled object , using extended state observer (ESO) estimating variation of the control system real-timely . then taking advantage of SMITH predictor characteristics that compensate the closed loop system of large delay, improve the ADRC control performance in the network-induced delay further. Matlab/TrueTime network control experiments show that: ADRC-SMITH control method can effectively decrease induced delay of network control systems.

Introduction

Control Systems Network (NCS) is a closed loop feedback control system which is formed by the network. Compared with the traditional control system, NCS has many advantages, such as remote monitoring and control, flexible system configuration, easy installation and maintenance, etc. But the time delay of network communication protocol, which is inevitable to produce communication delay, not only makes the system's performance greatly reduced, but also may cause the system to be unstable or even out of control [1,2]. From the point of view of stochastic control and dynamic programming, the paper analyzes and designs the network control system with time delay, but the premise is to know the statistical characteristics of time delay, and because of the large number of mean and variance of the operation, when the delay is large, the computation becomes quite complex [3].

In this paper, a class of network control system with time delay greater than the sampling period is studied. The control system is based on the control system of the ball and the ball delay network control system. This control method can effectively make use of self immunity algorithm does not depend on the controlled object mathematical model and achieve the advantages of good control, at the same time it can use Smith method will delay controlled process output lead time tau reflect to the controller, so as to achieve the effect of compensation. The experimental results show that the method is robust.

Description of Problem

In the networked control systems, when data from source node to destination node, time delay is mainly composed of tau SC and tau Ca, which tau SC is sensor to control

Communication delays between, tau CA is controller to perform the communication delay and record the time delay for tau k = tau SC tau CA; H system sampling period. Network control system structure as shown in figure 1.

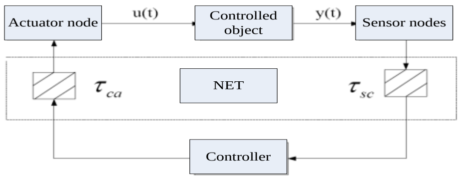

Figure 1 the structure of Network control system

The control performance of the network is studied by using the discrete time state space model. In this paper, we use the following mathematical model to express the control object ,

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{1}$$

$$y(t) = Cx(t) + Du(t) \tag{2}$$

In (1) and (2): state variables X (T) in RN; control input U (T) e RM; system output y (T) epsilon RR; a, B, C, D is the appropriate dimension matrix.

In fact, it is reasonable to use the method of discrete time system to analyze the NCS in the network control system. Take the time delay system for K, h< and K <2h of tau, discretization is:

$$x[(k+1)h] = \Phi(h)x(kh) + \Gamma_0(h,\tau_k)u(kh) + \Gamma_1(h,\tau_k)u[(k-1)h] \tag{3}$$

$$y(kh) = Cx(kh) + Du(kh) \tag{4}$$

Formula (3): $\Phi(h) = e^{Ah}$, $\Gamma_0(h,\tau_k) = \int_0^{h-\tau_k} e^{As} ds B$, $\Gamma_1(h,\tau_k) = \int_{h-\tau_k}^{h} e^{As} ds B$

ADRC-SMITH Predictive Control Basic Principle

3.1 Auto Disturbance Rejection Control Technology

The auto disturbance rejection control technology is a kind of nonlinear control method. Many unknown factors in the system are used as the "disturbance", and the ESO is used to estimate and compensate the dynamic system. The dynamic performance of the system is improved by using the feedback linearization of the dynamic system and the feedback control (NSEF) and the nonlinear state error feedback (TD). The general structure of auto disturbance rejection control is Figure 2 :

3.2 SMITH Predictor[5]

Smith predictive control strategy is a kind of predictive compensation control scheme, the basic idea of the method is pre estimate the dynamic characteristics of the system under the perturbation, then by estimation of time delay compensation, trying to make is delayed by the overshoot advance reflected to the regulator, allows the regulator action in advance, thus arrived eliminate time delay caused by the impact, reduce the overshoot of the system, improve the system stability, as shown in Figure 3 .

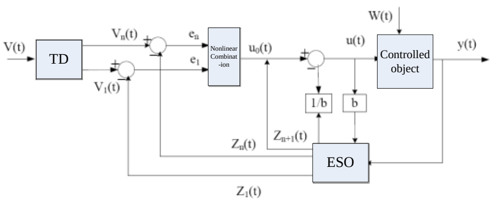

Figure 2 the structure of ADRC

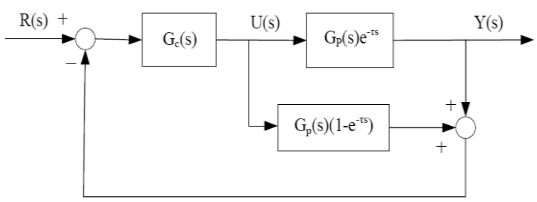

Figure 3 SMITH Predictor Principle

The system of the original system is compensated by SMITH and the closed-loop transfer function is:

$$\Phi(s) = \frac{G_c(s)G_p(s)}{1+G_c(s)G_p(s)} e^{-\tau s} \tag{5}$$

After the system compensation, a simple phase shift is only simple, which basically eliminates the effect of the pure time delay part on the control system.

3.3 ADRC-SMITH controller structure

According to the principle of auto disturbance rejection technique and SMITH predictor, a practical network control technology ADRC-SMITH predictor controller is obtained. As shown in figure 4.

Network control system design framework

(1) controlling the transmission network and the controlled object as the control object, controlling the network time delay variation will directly affect the mathematical model of the control object. As shown in figure 5.

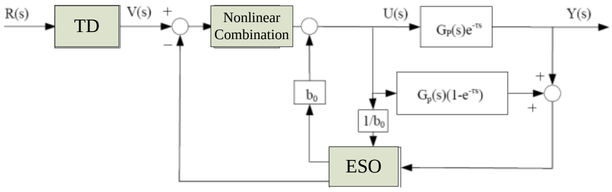

Fig. 4 principle of ADRC-SMITH predictor controller

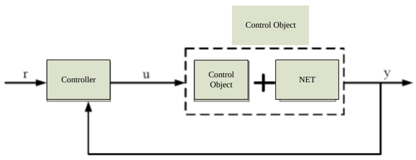

Figure 5 Control Model Chart

(2) the induced delay of the system is unified to the control object, and the other nodes of the network are not produced with time delay. The sensor nodes are driven by time and the other nodes are used event driven.

Modeling of network control system for cue ball

In the network environment, the model of the network control system is carried out with the ball and beam system as the experimental object. The mathematical model of the ball and beam system is:

$$\begin{cases} \dot{x} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} X + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t) \\ y = [1 \quad 0]x \end{cases} \tag{6}$$

Take the sampling period h = 0.01s, and Delay τ_k <h were controllable judgment, structure matrix S = [B AB], obtained RankS = 2, for the full rank matrix, the equation (9) is controllable state equation. Formula (6) controllable transform standard:

$$\begin{cases} x[(k+1)h] = \begin{bmatrix} 0 & -0.02 \\ 0.02 & -0.04 \end{bmatrix} x(kh) + \begin{bmatrix} -\frac{\tau(\tau-0.02)}{0.02} & \frac{\tau^2}{0.02} \\ -\tau & -2\tau \end{bmatrix} x(kh) + \begin{pmatrix} 0 \\ f_1(\tau_k) \end{pmatrix} u(kh) + \begin{pmatrix} 0 \\ f_2(\tau_k) \end{pmatrix} u[(k-1)h] \\ y(kh) = [1 \quad 0]x(kh) \end{cases} \tag{7}$$

Equation (7) can be obtained transformation:

$$\begin{cases} x_1(k+1) = -0.02x_2(k) \\ x_2(k+1) = 0.02x_1(k) - 0.04x_2(k) + x_3(k) \\ x_3(k+1) = \begin{bmatrix} -\frac{\tau_k(\tau_k-0.02)}{0.02} & \frac{\tau_k^{\,2}}{0.02} \\ -\tau_k & -2\tau_k \end{bmatrix} x(kh) + f_1(\tau_k)u(k) + f_2(\tau_k)u(k-1) \end{cases} \tag{8}$$

Network controller ADRC-SMITH integrated design and simulation

6.1 ADRC-SMITH controller design

6.1.1 Tracking design (TD)

In order to improve the dynamic quality of the control process, to avoid the adverse effect of the over large overshoot, the need to use TD to arrange the transition process. Its form is:

$$\begin{cases} fh = fhan(x_1(k)-v(k), x_2(k), r_0, h) \\ x_1(k+1) = x_1(k) + hx_2(k) \\ x_2(k+1) = x_2(k) + hfh \end{cases} \tag{9}$$

The function $fhan(z_1, z_2, r, h)$ is a nonlinear function.

6.1.2 extended state observer (ESO) design:

According to formula (9) analysis, we can know that there are some unknown terms in the control object state equation which is designed in this paper. On the state equation of mind

The uncertainty part is:

$$W(\tau_k) = \begin{bmatrix} -\dfrac{\tau_k(\tau_k-0.02)}{0.02} & \dfrac{\tau_k{}^2}{0.02} \\ -\tau_k & -2\tau_k \end{bmatrix} x(kh) + f_1(\tau_k)u(k) + f_2(\tau_k)u(k-1) \tag{10}$$

Then (10) the equation is changed to:

$$\begin{cases} x_1(k+1) = -0.02x_2(k) \\ x_2(k+1) = 0.02x_1(k) - 0.04x_2(k) + W_1(\tau_k) \end{cases} \tag{11}$$

The W(τ_k)expansion into a new state variable x3, then the state equation becomes:

$$\begin{cases} x_1(k+1) = -0.02x_2(k) \\ x_2(k+1) = 0.02x_1(k) - 0.04x_2(k) + x_3(k) \\ x_3(k+1) = \begin{bmatrix} -\dfrac{\tau_k(\tau_k-0.02)}{0.02} & \dfrac{\tau_k{}^2}{0.02} \\ -\tau_k & -2\tau_k \end{bmatrix} x(kh) + f_1(\tau_k)u(k) + f_2(\tau_k)u(k-1) \end{cases} \tag{12}$$

According to equation (12) is designed ESO is:

$$\begin{cases} e = z_1 - y,\ fe = fal(e, \alpha_1, \delta_0),\ fe_1 = fal(e, \alpha_2, \delta_0) \\ z_1 = z_1 + h(-0.02z_2 - \beta_{01}e) \\ z_2 = z_2 + h(z_3 - \beta_{02} fe + 0.02z_1 - 0.04z_2 + b_0u) \\ z_3 = z_3 - h\beta_{03} fe_1 \end{cases} \tag{13}$$

among them: $fal(e,a,\delta) = \begin{cases} e\delta^{a-1}, |e| \le \delta \\ |e|^a\ sign(e), |e| > \delta \end{cases} \quad \delta > 0$

Whereβ_{01}, β_{02}, β_{03}, α_1, α_2 is tunable ESO, just select the appropriate parameters, the ESO output $z_1 \to x_1$, $z_2 \to x_2$, $z_3 \to x_3$, that the completion of the unknown state W(τk)dynamic estimation.

6.1.3 Design of control rate:

$$u = fhan(z_1, cz_2, r, h_1) - \frac{z_3}{b_0} \tag{14}$$

In Formula (14) :c, r, h1, bo, is to be determined parameters.

6.1.4 SMITH predictor parameter settings:

Random Delay max（τ_k） = 0.014ms, the use of compensatory time lag $\tau = \tau_k/2$=0.007ms.

6.1.5 Set ADRC parameters: r0=1000,h=0.01,β01=200, β02=150,β03=100,α1=0.5, α2=0.5, compensation factor b0 = 1000, r = 10000, h1 = 0.01 damping ratio c = -25.

6.2 ADRC ADRC-SMITH algorithm and simulation comparison.

Using performance indicators E = 10000ts * σ% overall control performance evaluation, E smaller the better the performance. Experimental control performance comparison:

6.2.1 Network presence of random induced Delay 14ms

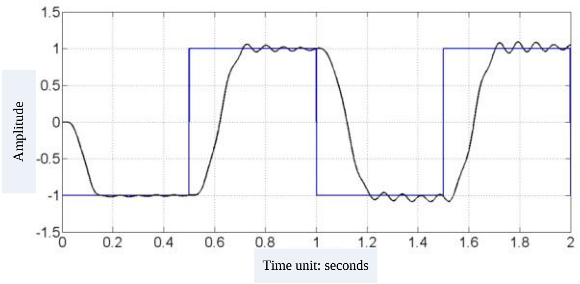

Figure 6 ADRC control effect E_{ADRC}=143.35

($t_p = 0.228s$ $t_s = 0.235s$ $\sigma\% = 6.1\%$)

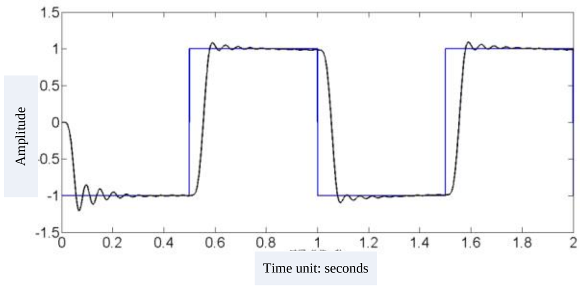

Figure 7 ADRC-SMITH control effect EADRC-SMITH = 28.32

($t_p = 0.236s$ $t_s = 0.213s$ $\sigma\% = 1.2\%$)

E_{ADRC} /$E_{ADRC\text{-}SMITH}$=5.06

The uncertainties in the observer of the extended state observer are shown in Figure 8

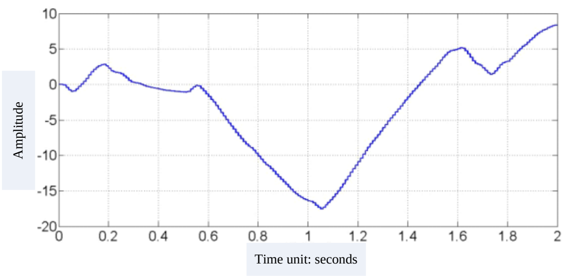

Figure 8 X3 uncertainty of ADRC

From the experimental results, ADRC-SMITH is better than the ADRC control method, especially in the time of 14ms random induction time delay, ADRC began to appear a small amplitude oscillation, and ADRC-SMITH still has excellent control performance. Self immunity extended state observer (ESO) is able to real-time estimation of a cause tau K for time delay systems with uncertainty variable X3,compensation for the control system.

Conclusion

In view of the characteristics of network control system, based on the analysis of network induced time delay, the network link and the controlled object are proposed as the control object, the network induced time delay is used as the object of uncertainty, and the ADRC-SMITH algorithm is used to simulate the TrueTime. Research shows that: the network link and the controlled object to be used as the control object to deal with is reasonable, the ADRC-SMITH algorithm can reduce the network induced time delay on the control system, has strong robustness, in the field of network control has a good development prospects.

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