Research and Simulation of Network Control System Smith Estimating PSD Control

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Abstract. Aiming at the universal problem of time-delay in the Network Control System (NCS) based on the better control of Smith predictive compensation to deal with time delay and the ability of single neuron adaptive PSD algorithm does not need identification process parameters, this paper proposes an intelligent Smith-PSD control based on single neuron adaptive PSD control algorithm and Smith predictive compensation algorithm. The simulation results show that the new controller has a strong robustness and self-adaptive, has desirable static and dynamic performance, and its performance is better than that of the regular single neuron PID control or single neuron Smith-PID control.

1. Introduction

Through the network sensors, controllers, actuators and other system components NCS (Networked Control Systems) forms a complex fully distributed closed loop feedback control system [1]. It has many advantages, such as less connections, high reliability and flexible structure, but the introduction of the communication network also brings an inevitable network-induced delay problem [2-4], that will cause system performance degrade even instability.

Single neuron PID control algorithm could understand the system's structure and parameters through their own learning, by adjusting parameters of the controller to achieve adaptive function. It has strong robustness and adaptability, but does not have the function that automatic adjustment the gain online. On the basis of the single neuron PID algorithm, the introduction of PSD (Proportional Summation Differential) algorithm is used to adjust the gain, constituting the single neuron PSD control algorithm.

In order to reduce the impact of time-delay, domestic and foreign scholars have made great efforts. In the literature [5], the use of buffer will transform the time-varying delay into a fixed maximum delay, expand the delay artificially and reduce the system sensitivity; In the literature [6], Markov chain was used to handle the problem of network-induced delay, the algorithm is too complex, inconvenient implemented; In the literature [7], the uncertainty of time-delay was translate into the uncertainty of parameter matrix, then a robust controller was design; The literature [8] proposed a dynamic smith predictor requires online identification network-induced delay; The literature [9] proposes an composited control algorithms based on improved expert PID control algorithm and Smith predictive compensation algorithm, assuming that the network delay is short.

In the delay-existing system, the traditional PID control is difficult to achieve the desired control performance, smith predictor controller can fully compensate for the delay system theoretically. However, it relies on the accurate model of the actual system, which to some extent limited its
application. In this paper smith predictor control method and the single neuron PSD control was combined, on the basis of the better control of smith predictive compensation to deal with time delay, the online learning and adaptive ability of single neuron PSD control can make up for the lack of Smith Predictor in the system without accurate mathematical model, the simulation results show that the method has good adaptability and robustness.

2. SIGLE NEURON PSD ALGPRITHM

2.1. PSD adaptive algorithm

Based on the geometric characteristics of the process error performance, Marsik and Strejc proposed PSD adaptive algorithm without identification process parameters[10,11], by detecting the actual output and the expected output simply, this algorithm can form a closed-loop. The incremental form of the control algorithm is given by formula (1).

\[ \Delta u(t) = K(t)[e(t) + \alpha \Delta e(t) + \beta \Delta^2 e(t)] \]

Where, is the gain of controller, are the scale factor and differential coefficient respectively, and are the error of control process, first difference and the second difference of error respectively, that constitute the input signal of the controller. Let:

\[ x_1(t) = e(t) = R(t) - \bar{Y}(t) \]  
\[ x_2(t) = \Delta e(t) = e(t) - e(t-1) \]  
\[ x_3(t) = \Delta^2 e(t) = e(t) - 2e(t-1) + e(t-2) \]

According to the changes of controlled object structure and parameters, according to the principle that all the absolute average of incremental control rate are equal, parameter and can adjust themselves automatically, that is:

\[ \alpha = \frac{\bar{e}(t)}{\Delta e(t)} = \frac{\bar{e}(t)}{\Delta^2 e(t)} \]  
\[ \beta = \frac{\bar{e}(t)}{\Delta e(t)} = \frac{\bar{e}(t)}{\Delta^2 e(t)} \]

Assuming that:

\[ T_e(t) = \frac{\bar{e}(t)}{\Delta e(t)} \quad T_v(t) = \frac{\bar{\Delta e(t)}}{\Delta^2 e(t)} \]

Then:

\[ \beta = \frac{\bar{e}(t)}{\Delta^2 e(t)} = \frac{\bar{e}(t)}{\Delta e(t)} \frac{\bar{\Delta e(t)}}{\Delta^2 e(t)} = T_e(t)T_v(t) \]

Marsik and Strejc deduced the recursive form of and as follows:

\[ \Delta T_e(t) = L \text{sign}(\bar{e}(t) - T_e(t-1)\bar{\Delta e(t)}) \]
\[ \Delta T_v(t) = L \cdot \text{sign}[|\Delta e(t)| - T_v(t-1)|\Delta^2 e(t)|] \]  

(10)

Among them, \(0.05 \leq L \leq 0.1\).

A lot of application experience has shown that the optimal ratio of \(T_e(t)\) and \(T_v(t)\) is 2:1, then the control law can be rewritten as:

\[ \Delta u(t) = K(t)[e(t) + 2T_v(t)\Delta e(t) + 2T_v(t)\Delta^2 e(t)] \]  

(11)

The iterative algorithm of \(K(t)\) as follows:

when \(\text{sign}(e(t)) \neq \text{sign}(e(t-1))\),

\[ K(t) = 0.75K(t-1) \]  

(12)

when \(\text{sign}(e(t)) = \text{sign}(e(t-1))\),

\[ K(t) = K(t-1) + c.K(t-1)/T_v(t-1) \]  

(13)

Among them, \(0.025 \leq c \leq 0.05\).

The formula (12) and (13) show that, when \(e(t)\) and \(e(t-1)\) has the same number, it will reduce the error rapidly; when \(e(t)\) and \(e(t-1)\) do not have the same number, the value of \(K(t)\) becomes 75% \(K(t)\) of the previous time, which can inhibit the increase of the overshoot effectively.

2.2. Single neuron PSD control

Now use the PSD control algorithm to adjust the gain \(K\) in single neuron PSD control, constituting the single neuron PSD controller, its structure is represented on figure 1.

\[ \Delta u(t) = K(t)[\omega_1 e(t) + \omega_2 \Delta e(t) + \omega_3 \Delta^2 e(t)] \]  

(14)

Through adjust the weighting coefficients online, single neuron PSD control achieve adaptive function. The adjustment of weighting coefficients should balance the relationship between input,
output and control error, therefore we choose a supervised Hebb learning algorithm, represented by the following:

$$\omega_i(t) = (1-c)\omega_i(t-1) + \eta z(t)u(t)x_i(t)$$  \hspace{1cm} (15)$$

Where, c is a constant, $\eta$ is the learning efficiency, $z(t)$ is the error signal, let $z(t) = R(t) - Y(t)$. To ensure convergence and robustness of the single neuron PSD control, after standardization, these algorithms can be represented by the following:

$$u(t) = u(t-1) + K(t) \sum_{i=1}^{3} \omega_i'(t)x_i(t)$$  \hspace{1cm} (16)$$

$$\omega_i'(t) = \frac{\omega_i(t)}{3} \sum_{i=1}^{3} \omega_i(t)$$  \hspace{1cm} (17)$$

$$\omega_1(t) = \omega_1(t-1) + \eta_p z(t)u(t)x_1(t)$$  \hspace{1cm} (18)$$

$$\omega_2(t) = \omega_2(t-1) + \eta_i z(t)u(t)x_2(t)$$  \hspace{1cm} (19)$$

$$\omega_3(t) = \omega_3(t-1) + \eta_d z(t)u(t)x_3(t)$$  \hspace{1cm} (20)$$

where, $\eta_p$, $\eta_i$, and $\eta_d$ are learning rate of proportional, integral and differential respectively.

3. SMITH PREDICTIVE CONTROL ALGORITHM

Smith predictor algorithm compensate for the controlled object by the use of prediction model, try to make the controller get an adjustment amount without time delay, so as to overcome the impact of the delay to the control system on purpose[12,13]. Structure of control system with smith predictor shown in figure 2.

![Figure 2. Structure of NCS based on Smith predictor.](image)

In figure 2, $D(s)$ is the transfer function of the controller, the controlled object $G(s)$ is assumed to be known. $G_m(s)$ is the prediction model of $G(s)$, $e^{-rca}$ and $e^{-rca}$ the prediction model of $e^{rca}$ and $e^{rca}$ respectively, the system closed-loop transfer function can be represented by the following:

$$H(s) = \frac{Y(s)}{R(s)} = \frac{D(s)e^{-rca}G(s)}{1 + D(s)G_m(s)(1 - e^{-rca} + rca) + D(s)G(s)e^{-rca} + rca}$$  \hspace{1cm} (21)$$
The formula (21) shows that, when \( \tau_{ca} = \tau_{scm} = \tau_{sc} = \tau \), \( G_m(s) = G(s) \). Prediction model exactly matches with the controlled object, then the transfer function shown as formula (22).

\[
H(s) = \frac{Y(s)}{R(s)} = \frac{D(s)G(s)}{1 + D(s)G(s)} e^{-\tau \zeta} s
\]  

(22)

The formula (22) shows that the characteristic equation of the system no longer contains the delay loop, achieved a complete compensation of the network delay. At this point, figure 2 can be equivalent to figure 3.

![Figure 3. Equivalent structure of NCS based on Smith predictor](image)

When \( \tau_{cam} = \tau_{ca} \), \( \tau_{scm} = \tau_{sc} \), \( G_m(s) = G(s) \) is not all true, The prediction model and the controlled object can not be an exact match, at this case characteristic equation also contains time delay, that will result in poor stability even divergent.

4. DESIGN COMPLEX CONTROLLERS

Single neuron PSD controller not only has the self-learning and adaptive function, but also can adjust the gain online, has good adaptability and robustness. But there is a big defect in delay compensation. Smith predictor controller can fully compensate for the delay system theoretically, but its over-reliance on accurate mathematical model of the controlled object which greatly limits its use. Therefore, this paper Style and spacing designs a smith-PSD predictor controller based on single neuron PID controller and smith predictor controller, its structure is shown as figure 4.

![Figure 4. Structure of network control system based on complex controller](image)

Figure 4 shows that, the control strategy of a single neuron smith-PSD controller can be divided into two parts: smith predictor control and single neuron PSD control. At the end of a control cycle, the output of the single neuron PSD controller will be compensated by the prediction model of smith predictor controller firstly, so that the controlled amount with lag time can be reflected to the single neuron PSD controller, then PSD controller get an adjusted amount with no lag time in the next control cycle. So that the whole system could get a good dynamic and static performance.

5. SIMULATION AND ANALYSIS

In order to evaluation on control effect of single neuron smith-PSD controller, in the Matlab environment, combined with the TruTime\[14,15\] package and Simulink, then established a system
model, on the base of models having been built, in the case of time delay exist simulations with different controllers are performed.

Selected a typical second-order system as a controlled object, and its transfer function is:

\[ G(s) = \frac{k}{as^2 + bs + c} = \frac{1000}{s^2 + s} \]

where, K is a gain magnification. The controller and actuator are set to the event-driven, the sensor is set to clock-driven. Sampling period T takes 10 ms, select the single neuron PID controller parameters: \( K = 4, \eta_1 = 11, \eta_2 = 0.1, \quad \eta_3 = 7500, \omega_n(0) = 122, \omega_z(0) = 3, \omega_l(0) = 35 \); Select the single neuron PSD controller parameters: \( K = 4, \tau_r(0) = 2000, c = 0.05, L = 0.1, \eta_1 = 11, \eta_2 = 0.1 \); Set network-induced delay variation between 1 ms and 4 ms respectively, unit step response based on three different controller shown in figure 5, then reset network-induced delay variations between 4 ms and 9 ms, the node driven modes and sampling time remain unchanged, unit step response based on three different controller shown in figure 6.

From figure 5 and figure 6 it can be seen, the single neuron PID control has a larger overshoot, when the time delay increases, the overshoot is further increased, and the settling time becomes longer, the PSD algorithm is incorporated to adjust the gain on the basis of a single neuron PID-Smith algorithm, overshoot of the system reduced significantly, making the entire process more smooth, the transition time has been reduced, the control effect has been further improved. When the network-induced delay increases, the control effect of the algorithm did not change significantly, still has strong adaptability and robustness, the delay larger the advantages were more obvious. When the delay changes between 4 ms and 9 ms, Adaptive process of the gain of single neuron smith-PSD proportional algorithm shown in Figure 7.
In order to further study adaptability and robustness of single neuron smith-PSD predictive control, in the same network parameters, set induced delay changes between 4ms and 9ms and keep the smith predictive model remains unchanged, the gain k of controlled object is reduced by 35%, so that prediction model and the actual plant model mismatch, the unit step response of the system shown in figure 8. network control system based on single neuron smith-PSD predictive controller still shows strong adaptability and robustness, response time and control precision can meet the requirements of quality control.

6. CONCLUSIONS

In this investigation, based on single neuron PID control algorithm and smith predictive control algorithm the single neuron smith predictor PSD control strategy was proposed. This algorithm is simple and have strong adaptive ability, the system design without the need for accurate model of the controlled object. Simulation results show that, in networked control system, the single-neuron predictive control has the high stability and regulation precision are better than the single neuron PID controller and a single neuron PID-Smith estimates controller.

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