Optimization Design of Networked Control System with Communication Interference

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Abstract. For network control systems with long delay and packet loss, firstly, it is based on the effectiveness of model-based control in network systems with long delay, and it also establish a feedback model that simulates delay as a system component. Considering the possible modeling errors of the feedback model, a design of the traditional linear system is proposed to design the controller by using the communication interference observer to compensate for the delay characteristics. Then, the steady-state error of the characteristic equation of the system is obtained and prove the feasibility and robustness of the method, and carried out the equivalent analysis of packet loss. Finally, the effectiveness of the controller is demonstrated by the simulation of communication interference data from comparing with the Smith predictor.

1. Introduction

Network Control System (NCS) refers to a closed-loop feedback control system formed by a communication network connection. The main components are controllers, controlled objects, sensors and actuators, etc. The module composed of this system component is used as a network node to access the network, so it forms a new closed loop. The network control system has the advantages of less wiring and lower cost compared with the traditional point-to-point wired control system. Even in the face of complex environments, it is easy to install, maintain, and expand [1-2]. However, due to the introduction of communication networks, some unstable factors of the network will also be brought into the control system [3-5].

Due to the introduction of the network, it is necessary to avoid and reduce the impact on the control system. In recent years, the academic community has also done a lot of research on some problems about the network control system [6-8]. These studies have reduced key issues such as network inducing delay and packet loss in different directions [9]. Document uses Markov-based stochastic process to describe the characteristics of system packet loss. A time-varying controller based on the principle of packet loss and capable of compensating for the steady-state error of the system is designed [10]. Literature uses state augmentation to overcome the impact of delay on network control system analysis. Then consider the random packet loss situation and convert the augmentation system into a switching system. Based on this, a network robust controller design method is proposed.

This paper adopts a model-based network control system to compensate for long delay and packet loss. The problem of existence of model feedback errors and simultaneous time delay and packet loss is studied. Design controllers by using the traditional linear system, design method by using the Communication Disturbance Observer (CDOB) [11]. Then separate the controller and model error.
feedback module on both sides of the network. The research on communication interference shows that the method has good robustness. The final data simulation also verified that the controller design was effective [12].

2. Questions and main content

Consider designing a Communication Disturbance Observer (CDOB) to eliminate the effects of time delays on the system, and this communication interference observer can also effectively compensate for time delays. According to Figure 1, important conclusions can be drawn. The transfer function $G_{cl}(s)$ from $Q(s)$ to $W(s)$ is as shown in equation (1).

$$G_{cl}(s) = \frac{C(s)D(s)e^{-ds}}{1+C(s)D(s)}$$

(1)

Where $C(s)$ is the controller at the near end of the network, $d$ is the actual time delay, and $D(s)$ is simply a separate transfer function of the remote controlled object of the network. Assume that $B(s)=1$, the low-pass filter converter in the block diagram, has a high frequency cutting efficiency. Since the compensation of CDOB is obtained, and it can be seen from equation (1) that the time delay element $e^{-ds}$ exists only in the numerator of the fraction, and because there is no time variable in the characteristic polynomial, the design of the conventional linear system is adopted here. The controller $C(s)$ method is designed for the controllers in this section.

3. Assume the impact of the error

Considering that modeling errors may affect the communication disturbance observer. When there is a modeling error in the inverse model of the structure of the CDOB in Figure 1. The basic structure of Figure 1 will be converted into the structure shown in Figure 2. Where $\tilde{D}(s)$ is the key model, its role is to identify the controlled object and feedback information to the controller. The closed-loop transfer function $G_{cl}(s)$ from the data input $Q(s)$ to the information output $W(s)$ in Figure 2 is obtained as in equation (2).
\[ G_{cl}(s) = \frac{C(s)D(s)e^{-dt}}{1 + C(s)\tilde{D}(s)} \quad (2) \]

\[ E(s) = Q(s) - G_{cl}(s)Q(s) = \frac{C^{-1}(s) + (\tilde{D}(s) - D(s)e^{-dt})}{C^{-1}(s) + \tilde{D}(s)}Q(s) \quad (3) \]

In the equation (3), \( E(s) \) is the deviation between the target data \( Q(s) \) at the time of system input and the information \( W(s) \) at the time of system output.

Let \( Q(s) = \frac{1}{s} \), in the equation (4) obtain the steady-state error of the control input.

\[ \lim_{s \to 0} sE(s) = \lim_{s \to 0} s \frac{C^{-1}(s) + (\tilde{D}(s) - D(s)e^{-dt})}{C^{-1}(s) + \tilde{D}(s)} = \lim_{s \to 0} \frac{C^{-1}(s) + (\tilde{D}(s) - D(s))}{C^{-1}(s) + \tilde{D}(s)} \quad (4) \]

Assuming the system is stable and not modeled correctly and without errors, i.e. \( \tilde{D}(s) = D(s) \) , and \( C(s) \), \( D(s) \) or \( \tilde{D}(s) \) has a pole at the origin when there is no step input, then \( \lim_{s \to 0} sE(s) = 0 \), i.e. the system does not have a steady-state error. When \( \tilde{D}(s) \neq D(s) \), even if \( C(s) \) has a pole at the origin, the system will interrupt the feedback due to the presence of steady-state error. As shown in Figure 2, the controller cannot receive any feedback from the state of the object. Therefore, even if the output value of the object has a large deviation from the target value, the offset compensation cannot be adjusted to the controller.

4. Compensation method and steady state error

As shown in Figure 3, it is the system model after setting up the new controller. Where \( \tilde{D}(s) \) is the established model and \( F(s) \) is the model error feedback module. Even if there is an undetermined steady-state deviation between the object transfer function \( D(s) \) and the \( \tilde{D}(s) \) \( G \) of the feedback model.

In order to detect the stability of the method, simulate the interference of time delay on the closed-loop system by inputting a step signal to the target value \( Q(s) \). The transfer function of the system for obtaining \( Q(s) \) to \( W_p(s) \) simulation data from equation (5)

\[ \frac{W_p(s)}{Q(s)} = \frac{C(s)D(s)e^{-dt}(1 + F(s)\tilde{D}(s))}{(1 + C(s)\tilde{D}(s))(1 + F(s)D(s))} \quad (5) \]

There is no unknown function time delay element \( e \) in the denominator of equation (5). Therefore, the network near-end controller \( K(s) \) and the network far-end feedback model \( F(s) \) can be designed using the traditional linear time-invariant design method. Now suppose that the object
transfer function $D(s)$ and the system model $\tilde{D}(s)$ have poles at the origin, namely $D(s) = D'(s)/s$ and $\tilde{D}(s) = \tilde{D}'(s)/s$. Therefore, Equation (5) is transformed into equation (6).

$$\frac{W_p(s)}{Q(s)} = \frac{K(s)D'(s)e^{-ds}(s + F(s)\tilde{D}'(s))}{(s + K(s)\tilde{D}(s))(s + F(s)D(s))}$$

The input set in this system is step input, i.e. $Q(s) = 1/s$, the steady state error can be obtained in equation (7).

$$\lim_{s \to 0} s(Q(s) - W_p(s)) = \lim_{s \to 0} s\left(1 - \frac{W_p(s)}{Q(s)}\right)Q(s) = \lim_{s \to 0} s\left(1 - \frac{C(s)D'(s)e^{-ds}(s + F(s)\tilde{D}'(s))}{(s + C(s)\tilde{D}'(s))(s + F(s)D(s))}\right)\frac{1}{s} = 0$$

Therefore, as can be seen from equation (8), the steady-state error of the system becomes zero at this time.

![Figure 4](image.png)

**Figure 4.** Structure of the impact of packet loss on system adjustment.

As shown in Figure 4, the environment is assumed to be a continuous input of the system for a certain period of time. The input mode can be zero. Assuming that time is discrete, continuous loss of data occurs when information is present in the network. At this time, the information $u(k)$ input to the controlled object becomes the $u(k-1)$ of the previous moment. And if the system input $u(k)$ is out of communication interference at time $k$, the communication interference is considered as $u(k) - u(k-n)$. However, the input value of the system object at time $k$ is still $u(k-1)$. It can be seen that the input and output of the system in these two cases is equivalent. Even if continuous packet loss occurs, the communication interference at the system input $u(k)$ can be regarded as $u(k) - u(k-1)$. The above discussion shows that packet loss is equivalent to communication interference in the CDOB, so the packet loss is compensated.

5. **Numerical simulation**

This section will use data simulation to verify the proposed method. For the consideration of the model parameters, the model error is simulated by the special deviation of the DC gain, so that the gain obtained by $D_m$ is larger than the gain obtained by $D_p$.

$$D_m = \frac{240}{152s(s + 780)}, \quad D_p = \frac{140}{152s(s + 780)}$$

Since the controller $K(s)$ and the error feedback model $F(s)$ of the method are designed as separate units. Therefore $K(s)$ and $F(s)$ are set to be implemented as follows: $K(s) = 45 + 10s, \quad F(s) = 45 + s$.
In order to evaluate the compensation effect of the proposed method for long delay, the Smith predictor was added to the simulation for comparison. So the sampling period for the simulation is set to \( T = 0.001\,\text{s} \). Set a longer time delay \( d(k) = 4\,\text{s} \). The simulation results are shown in Figure 5.

![Figure 5. Feedback delay curve of time delay on system state.](image)

A clear conclusion can be drawn from Figure 5. When the controller input signal is issued and the system network has a delay. In this paper, the controller design method can successfully reach the signal position. Moreover, it can be seen that this method can achieve the ideal target value faster than the Smith predictor. Although there are some very slight deviations after reaching the target value, the system is able to correct itself very quickly. So in some cases this method has better features.

![Figure 6. Status trajectory of the system after communication interference.](image)

In order to detect whether the proposed method is robust in the case of system packet loss. Assume that the time delay is evenly distributed, i.e. \( d(k) = 0.12\,\text{s} \), and the upper and lower limits of the boundary value are set.

\[
d_{\text{max}}(k) = 3.50\,\text{sec}, \quad d_{\text{min}}(k) = 3.20\,\text{sec}
\]

Since the time delay is set to be evenly distributed, it is not considered for the time being.

\[
K(s) = 9s + 450, \quad F(s) = 9s + 450
\]

Figure 6 shows the impact of packet loss testing on system stability. Where the yellow line is the curve of the proposed method. It can be clearly seen that good stability can be maintained even in the case of a serious packet loss rate of 10% in a short time. The above simulation experiments verify the robustness of the proposed method to packet delay, network packet loss and model error.

6. Conclusion
This paper is aimed at network control systems with long delay, packet loss and model establishment. Considering the error caused by modeling, a method of adding communication interference observer (CDOB) to the system is proposed to reduce the influence of communication interference. The method
uses a dual feedback mode, which to build a model on the remote controller side. This model feeds back information to both the near-end controller and the remote object; Model error feedback is established on the far-end object side to compensate for steady-state errors. Simulation experiments show that the controller model designed in this paper has good stability under various communication interferences.

References

[1] You K Y and Xie L H. Survey of recent progress in networked control systems J. Acta Automatica Sinica, 2013,39(2): 101-118.
[2] Zhang Dongmei, Yu Li and Zhou Minghua. Stabilization of Networked Control Systems with Fast Time-varying Delay and Packet Loss J. Control Theory and Applications, 2008, 25(3).
[3] Halder K, Das S and Dasgupta S. Controller design for networked control systems — An approach based on L2 induced norm J. Nonlinear Analysis Hybrid Systems, 2016,19: 134-145.
[4] Schenato L. Optimal estimation in networked control systems subject to random delay and packet dropout J. IEEE Trans on Automatic Control, 2008, 53(5): 1311-1317.
[5] Turner J R. Tow ards a theory of project management: The functions of project management J. Int J of Project Management, 2006, 24(3): 187-189.
[6] C. Tan, L. Li and H. Zhang: "Stabilization of networked control systems with both network-induced delay and packet dropout", Automatica, Vol.59, pp.194–199 (2015)
[7] Gao H J, Meng X Y and Chen T W. Stabilization of networked control systems with a new delay characterization J. IEEE Trans on Automatic Control, 2008, 53(9): 2142-2148.
[8] Wang J F and Yang H Z. Exponential stability of a class of networked control systems with time delays and packet dropouts J. Applied Mathematics and Computation, 2012,218(17): 8887-8894.
[9] Cai Yunze, Pan Ning and Xu Xiaoming. H∞ robust filtering for networked control systems with long delay and packet loss J. Control and Decision, 2010, 25(12).
[10] Zhang T Y and Liu G P. Tracking control of wheeled mobile robots with communication delay and data loss J. Journal of Systems Science & Complexity, 2018(4):1-19.
[11] Liu Yicai, Liu Bin and Zhang Yong. Stability Analysis of Networked Control Systems with Bilateral Random Delay and Packet Loss J. Control and Decision, 2017(9).
[12] Mao Z, Jiang B and Shi P. H∞ fault detection filter design for networked control systems modelled by discrete Markovian jump systems J. IET Control Theory and Applications, 2007,115(5): 1336-1343.