The Design of Compensators for Telecontrol System Based on Network

FAN Jianwei WANG Qi CUI Wei YANG Duwei

Department of Aerial Instrument and Electric Engineering

The First Aeronautical Institute of Air Force

Xinyang, China

fanjianwei_3@sohu.com

***Abstract*—The several kinds of compensators for telecontrol system are summarized in this paper. The dynamic compensator could change telecontrol system from unstable state to stable state, but performance will be influenced by prediction error of the network time delay and model error of object. The variable structure compensator only can get rid of the prediction of the network time delay. The influence of model error is still existed, and the variable structure compensator cannot be used for telecontrol system of UDP transport protocol. The new type compensator avoided the problem of model error of object and prediction of the network time delay, and cannot be used for telecontrol system of UDP or TCP transport protocol.**

***Keywords*— Network, Telecontrol system, Compensator, Time delay**

I. INTROUDUCTION

With the development of control, computer and network, the distance of control system has been extended, which constitutes the telecontrol system based on network. In the telecontrol system, the network exists in the forward path and feedback path of control system to transmit control signals and feedback signals. Therefore, this kind of systems can control any object interconnected with the network in any time and any place.

The telecontrol system can be depicted in Fig. 1. Network exists in the forward path and feedback path. Control signals and feedback signals transfer through Network.

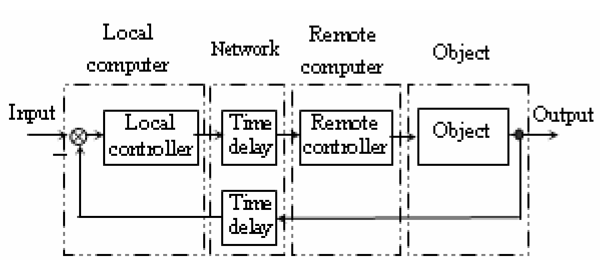

Figure 1. Net based telecontrol system

The network time delay in the forward path and feedback path exists in the process of signals transfer, which will affect the stability of telecontrol system. To eliminate the influence of time delay, the compensator is installed in network based telecontrol system [1]. Signasl are sent in a sampling period in the local computer and remote computer.

Mechatronics center at Beijing Institute of Technology has been researching Internet based telecontrol system from 1999, and has published papers on dynamic compensator that predicts the network time delay and fuzzy controller that does not rely on object model.

This paper summarizes three kinds of compensators, which are dynamic compensator, switched-compensator and the new type compensator, and makes comparison in control quality between them.

II. DYNAMIC COMPENSATOR

Fig. 2 shows the principle of dynamic compensator. $G_0(z)$ denotes object, and object model can be denoted as $\hat{G}_0(z)$. Network in the forward path can be denoted as $z^{-m(i)}$, and network in the feedback path can be denoted as $z^{-n(j)}$. The prediction of $z^{-m(i)}$ can be denoted as $z^{-s(i)}$, and the prediction of $z^{-n(j)}$ can be denoted as $z^{-l(j)}$. $u_b(z)$ denotes control signals, and $f(z)$ denotes feedback signals, and $f_1(z)$ denotes the signals that compares with reference input.

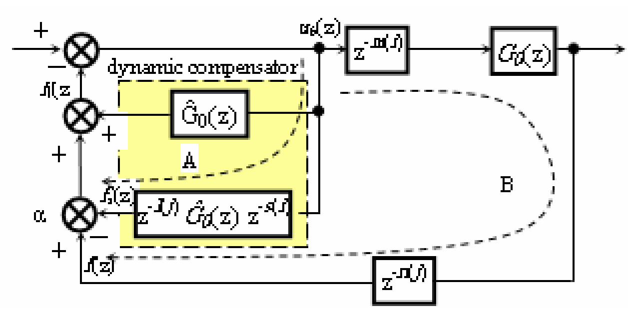

Figure 2. Telecontrol system with dynamic compensator

Two circuit that are A and B exist between signals $u_b(z)$ and the point of comparison α. The circuit A is the function $z^{-l(i)}\,\hat{G}_0(z)\,z^{-s(j)}$ The circuit B consists of network in the forward path $z^{-m(i)}$, object $G_0(z)$, and network in the feedback path $z^{-n(j)}$. If object model can describe object precisely and predictor of network time delay can predict precisely, circuit A equals circuit B. It means that equation $f(z)=f_s(z)$ is satisfied. Signal $f_l(z)$ equals feedback signal of closed-loop control system without network, and signal $u_b(z)$ equals control signal of closed-loop control system without network. If closed-loop control system without Internet is stable, the stability of Internet based telecontrol system can be guaranteed.

Predictor of network time delay can obtain the data of $l(i)$ and $s(j)$, plant model can be obtained by system identification. But to predictor of network time delay, dynamic compensator needs to solve the problem of time synchronization between local computer and remote computer. It is very difficult to make the deviation of time synchronization less than 1 ms by software, which is demanded by the control system.

Because dynamic compensator includes prediction of network time delay and plant model, prediction error and model error will affect the control performance.

III. THE VARIABLE STRUCTURE COMPENSATOR

Fig. 3 illustrates the telecontrol system with variable structure compensator. Transfer function of object can be denoted as $G_0(z)$. Network in the forward path can be denoted as $z^{-m(i)}$, and Internet in the feedback path can be denoted as $z^{-n(j)}$. Variable structure compensator includes plant model $\hat{G}_0(z)$ and regulator Φ.

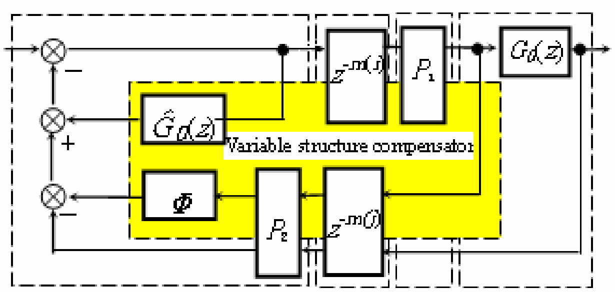

Figure 3. Telecontrol system with Variable structure compensator

Because of matching problem of network time delay and sampling period, more-sampled case and empty-sampled case exist in the forward path and feedback path. More-sampled case and empty-sampled change the time series of control signal and feedback signal, which will affect control performance inevitably. The sampled-information processor P_1 and P_2, are installed in the datagram sink of local computer and remote computer separately so as to transact in the more-sampled case and empty-sampled case.

Structure of regulator Φ is switched based on time delay. The output signal of regulator Φ will compare with feedback signal. If the value of comparison is zero, the network time delay is compensated.

Variable structure compensator avoids prediction of network time delay, and the problem of prediction of the network time delay and the problem of time synchronization are avoided.

However, this compensator still relies on object model. And the same time, if control signals or feedback signals are lost in network, the regulator Φ can not compensate the network time. The variable structure compensator cannot be used for telecontrol system of UDP transport protocol, because the signals are easy to lost in UDP transport protocol.

IV. THE NEW TYPE COMPENSATOR

Fig. 4 illustrates the telecontrol system with the new type compensator. $G_0(z)$ denotes object, and object model can be denoted as $G_m(z)$. Network in the forward path can be denoted as $z^{-m(i)}$, and network in the feedback path can be denoted as $z^{-n(j)}$. The sampled-information processor of forward path can be denoted as $P_1(z)$, and the sampled-information processor of feedback path can be denoted as $P_2(z)$. The output of object can be denoted as $Y(z)$, and the output of object model can be denoted as $Y_m(z)$.

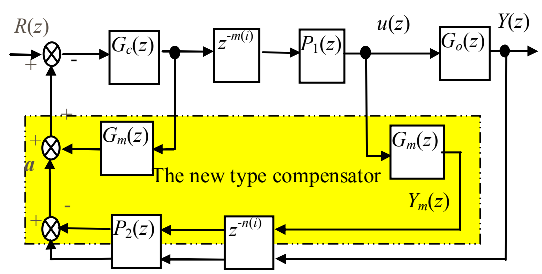

Figure 4. Telecontrol system with new type compensator

The closed loop transfer function of the telecontrol system can be denoted as:

$$Y(z)/R(z)=[G_c(z)z^{-m(i)}P_1(z)G_o(z)]/\{1+G_c(z)G_m(z)+G_c(z)z^{-m(i)}P_1(z)[G_o(z)-G_m(z)]z^{-n(i)}P_2(z)\} \tag{1}$$

The characteristic equation is:

$$1+G_c(z)G_m(z)+G_c(z)z^{-m(i)}P_1(z)[G_o(z)-G_m(z)]z^{-n(i)}P_2(z)=0 \tag{2}$$

To compensate the network time delay, from the characteristic equation we can conclude:

$$G_c(z)z^{-m(i)}P_1(z)[G_o(z)-G_m(z)]z^{-n(i)}P_2(z)=0 \tag{3}$$

If object model can describe object precisely, then:

$$G_o(z)=G_m(z) \tag{4}$$

The characteristic equation can be written:

$$1+G_c(z)G_m(z)=0 \tag{5}$$

Because the network time-delay doesn't exit in the characteristic equation, which doesn't affect the stability of telecontrol system, the network time-delay is compensated.

Whether control signals or feedback signals are lost in network or not, the new type compensator compensates the network time-delay. The new type compensator does not depend on the prediction of the network time delay and time synchronization, and the same time the new type compensator can be used for telecontrol system of any transport protocol, UDP transport protocol or TCP transport protocol.

However, this compensator still relies on object model. Because the environment around the object will disturb the object, the characteristic of object is changed. Then the object model can not describe object precisely.

To resolve model error, single neuron adapting control is added in telecontrol system. Fig. 5 illustrates the telecontrol system with compensator and adapting control. $G_a(z)$ denotes adapting control. $e(k)$ denotes the output error of object and its model.

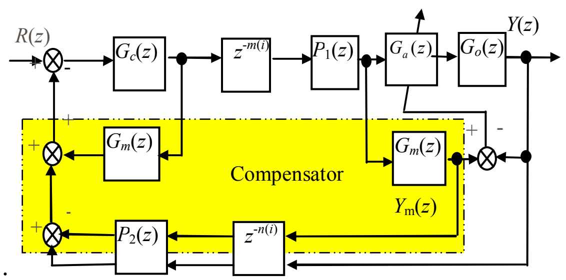

Figure 5. Telecontrol system with compensator and adapting control

The arithmetic of adapting control is single neuron adapting PID control. When the characteristic of object is changed, the error $e(k)\neq 0$, the error $e(k)$exports to adapting control $G_a(z)$. The adapting control makes the output of object to be equal the output of its model. When the error $e(k)=0$, the adapting control is disabled.

The arithmetic of adapting control is single neuron adapting PID control can be denoted follow equations：

$$u(k)=u(k-1)+K\sum_{i=1}^{3}\overline{w_i}(k)x_i(k) \quad (6)$$

$$\overline{w_i}(k)=\frac{w_i(k)}{\sum_{i=1}^{3}|w_i(k)|} \quad (7)$$

$$w_1(k+1)=w_1(k)+\eta_I z(k)u(k)x_1(k) \quad (8)$$

$$w_2(k+1)=w_2(k)+\eta_P z(k)u(k)x_2(k) \quad (9)$$

$$w_3(k+1)=w_3(k)+\eta_D z(k)u(k)x_3(k) \quad (10)$$

$$x_1(k)=y_m(k)-y(k)=e(k) \quad (11)$$

$$x_2(k)=\Delta e(k)=e(k)-e(k-1) \quad (12)$$

$$x_3(k)=e(k)-2e(k-1)+e(k-2) \quad (13)$$

$$\mathbf{z}(k)=x_1(k)=e(k) \quad (14)$$

where K as proportional coefficient, $K>0$,differential coefficient.

η_P、η_I、η_{Da} as proportional, integral and differential learning speed.

When single neuron adapting control is added in telecontrol system, the closed loop transfer function of the telecontrol system can be denoted as:

$$Y(z)/R(z)=G_c(z)\cdot z^{-m(i)}P_1\cdot G_a(z)\cdot G(z)/\{1+G_c(z)G'(z)+ G_c(z)z^{-m(i)}P_1[G_a(z)G(z)-G_m(z)]z^{-n(i)}P_2\} \quad (15)$$

The characteristic equation is:

$$1+G_c(z)G'(z)+G_c(z)z^{-m(i)}P_1[G_a(z)G(z)- G_m(z)]z^{-n(i)}P_2=0 \quad (16)$$

To compensate the network time delay, from the characteristic equation we can conclude:

$$G_c(z)z^{-m(i)}P_1(z)[G_a(z)G_o(z)-G_m(z)]z^{-n(i)}P_2(z)=0 \quad (17)$$

If function of the adapting control is valid, then:

$$G_a(z)G_o(z)=G_m(z) \quad (18)$$

Thus Fig. 5 is equivalent with Fig. 6

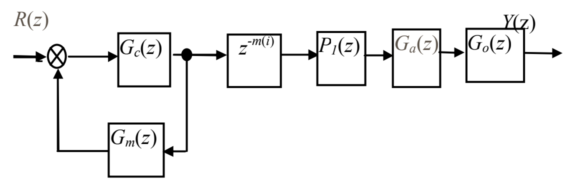

Figure 6. Equivalent diagram

From Fig. 6 we can conclude that the telecontrol system with compensator and adapting control can resolve the problem of model error.

V. EXPERIMENTAL RESULTS

The network time delay in the forward path and feedback path in the experiment is illustrated in Fig. 7 and Fig 8. Those data are corresponding to datagram transmission in TCP protocol between Beijing and Tokyo.

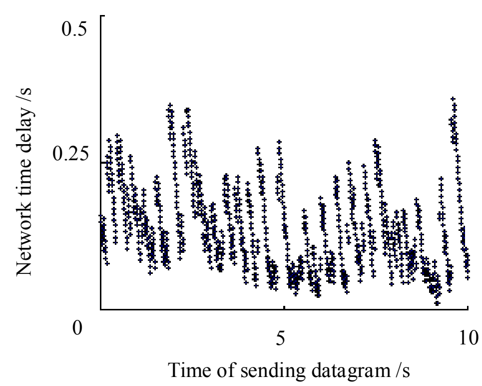

Figure 7. Network time delay in the forward path

The object is the servo valve controlled hydraulic cylinder. Output signal is position of the hydraulic cylinder. In order to guarantee the unanimousness of experiment condition and in comparison with different experiment results, network time delay simulation is performed at first.

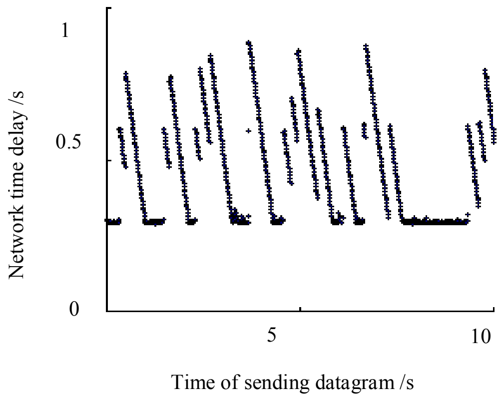

Figure 8. Network time delay in the feedback path

The experiment conditions are: oil pressure is 5MPa, and oil temperature is 30℃. Sampling period is 10ms. Object model is shown as following equation, which is obtained by system identification.

$$G_m(z)=\frac{0.005512\ z^{-1}+0.00777z^{-2}+0.003927\ z^{-3}}{1\text{-}0.338283z^{-1}\text{-}0.335196z^{-2}\text{-}0.326521z^{-3}} \quad (19)$$

The value of the coefficients is initialized as the follow:

$w_1(0)$=500,$w_2(0)$=200,$w_3(0)$=100,K=50,η_D=100,η_P =50,η_I=20.

The unit step response in different condition of closed loop control system in experiment is shown in Fig. 9:

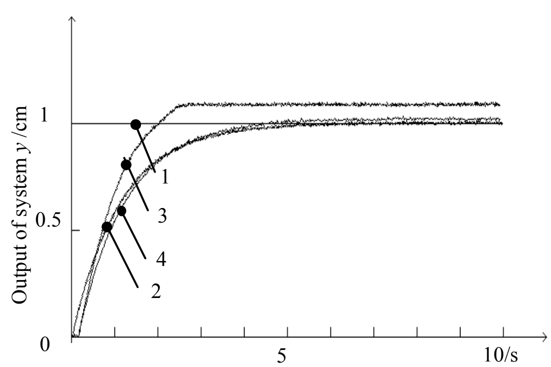

Figure 9. Step response of different condition

Curve 1 is the input signal of unit step.

Curve 2 is the unit step response of closed-loop control system without network time delay. There is a steady-state error in the output of system.

Curve 3 is the unit step response with the only compensator with network time delay shown in Fig. 7 and Fig. 8. By observing the step response shown in the experiment results, there is a steady-state error existed. Object model error is the main reason to engender steady-state error. On the side, the arithmetic of sampled-information processor $P_1(z)$ and $P_2(z)$ brings some steady-state error.

Curve 4 is the unit step response with the compensator and adapting control with network time delay shown in Fig. 7 and Fig. 8. There is a steady-state error existed also. The arithmetic of sampled-information processor $P_1(z)$ and $P_2(z)$ is the main reason to engender steady-state error. Designing appropriate arithmetic of sampled-information processor can eliminate steady-state error, which will be discuss in other paper.

By observing the step response shown in all the experiment results, we can include that telecontrol system with the compensator and adapting control can not only avoid prediction of network time delay, but also can resolve the problem of model error. The new type compensator is the base to study the telecontrol system in-depth.

VI. CONCLUSION

The network time delay and its uncertainty property affect the stability of network based telecontrol system. Prediction error and objcet model error will affect the control performance of telecontrol system with dynamic compensator and variable structure compensator.

Both experiment results and theory analysis prove that the new type compensator and can compensate the network time delay in the telecontrol system, at the same time reduces the influence of model error to telecontrol system. Application show the method has a strong robustness and better controlling character.

REFERENCE

[1] X.F. Wang, P.D. Wu, "Basic study of hydraulic telecontrol system based on Internet," The Proceedings on Spring Conference of Fluid Power System Society of Japan, pp. 4-6, June 2002. Engineering and Application, pp.227-229, April 2003.

[2] X.F. Wang, P.D. Wu, C.Q. Ren et al, "Simulation study on dynamic compensator in telecontrol system based on TCP/IP," Journal of Beijing Institute of Technology, pp.695-698, June 2002.

[3] C.Q. Ren, P.D. Wu, X.F. Wang et al, "Research of choice of protocol and drive methods in telecontrol system based on Internet," Chinese Journal of Mechanical Engineer, pp.122-125, Augest 2002.

[4] X.F. Wang, P.D. Wu, C.Q. Ren et al, "The application of fuzzy control in TCP/IP based telecontrol system," Computer Application, pp.83-85, November 2002.

[5] C.Q Ren, P.D. Wu, S.Y. Ma et al, "Research of forecast arithmetic of hydraulic telecontrol system based on Internet," Proceedings of The 2001 International Symposium on Advanced Engineering, pp.82-87, October 2001.