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Mechanical remote control technology based on artificial intelligence[1]

Bo Cui[2], Xianchuang Fan[2], Yuejiao Niu[2]

Abstract. For solving the uncertainty of data transmission, which reduces the operational performance of control system and results in the system instability, the deterministic control of robot arm network remote control system is studied. By introducing the receiving buffer, the random time-varying delay is converted to fixed delay, and then the controller is designed for the fixed time delay. The basic ideas of the three main methods of deterministic control, namely state predictive control, step-by-step transform control and predictive control are introduced. Through the corresponding state transitions, the relationship between the three methods is discussed, and the theoretical results are proved by the simulation experiment. The results showed that the obtained results are correct. Based on the above findings, it is concluded that the deterministic control is of great help in solving the uncertainty of data transmission in the networks.

Key words. Remote control, deterministic control, fixed time delay.

1. Introduction

With the high integration and rapid development of the information industry, the remote control technology is becoming more and more popular and widespread [1–2]. The remote control is to separate the controller and the controlled object in the physical position, and to adopt certain means of communication to realize the transmission of control information and feedback information [3]. Generally, when the operator is far away from the controlled objects, it will often use the remote control technology, especially in the complex, harsh and dangerous environment. The operator remotely controls the controlled object to complete the required planning and decision-making, which is able to reflect the advantages of remote control technology, such as space exploration, marine development, remote medicine, nuclear industry remote experiments and so on. Of course, in these special areas, remote control will have higher speed, reliability and security requirements. Because of the

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[2]School of Information & Engineering, North China University of Science and Technology, 030051, China

many applications of remote control, there are many kinds of communication means applied, such as space-based network, communication satellite, special optical cable, microwave and so on. The channel capacity, speed, transmission distance and application situations of various media are different, which makes the remote control system realize different functions and service objects [4–5]. In a network based remote control system, the transmission delay in the network is random and time-varying, so the whole system can be transformed into a stochastic system for the processing. Therefore, many scholars adopted the method of stochastic optimal control [6–7], used a linear stochastic system model to describe networked control systems with stochastic delay characteristics, and carried out linear two-order Gauss control. However, the stochastic control method requires that the network delay must obey a certain determined distribution. When the network delay does not obey a certain determined distribution, the stochastic control method is no longer applicable [8–9]. Luck and Ray [10] proposed a deterministic control idea, introduced the receive buffer, and transformed the random time-varying delay into fixed delay. And then in allusion to the fixed time delay, the controller is designed to solve the problem of uncertainty of the network delay. At present, the control methods of deterministic network remote control system mainly follow the three ideas of state predictive control [11], step change control [12] and Smith predictive control [13]. This paper introduces the three methods, and based on this, it focused on the research on state prediction control and staged transformation control based on state feedback, which combined with the infinite time two-order optimal controller. In addition, it proved the essence consistency of the two methods, and discussed the equivalence of the three control methods in the case that the system initial state is zero.

2. Method

2.1. State predictive control

According to Fig. 1, at the moment of kT, the controller receives the system state of $x(k)$, and the control law of $u(k)$ after operation is the moment of $(k+m)T$ when it is sent to the controlled object by the actuator, and at that time, the state of the controlled object has been changed to $x(k+m)$. Therefore, the idea of the state predictive control is that the controller, at the kT moment, uses the state equation of the controlled object to predict the system state of the $(k+m)T$ moment, and to send the control law in view of the state of the $(k+m)T$ moment.

Within the moments $(0, mT)$, because of the role of deterministic delay, the controlled objects cannot receive any control information. Starting from the mT moment, the actuator, with time as the T cycle, provided the control information $u(0)$, $u(1)$ and so on, for the controlled objects according to the order.

The system state $x(k)$ obtained at the moment of kT and the control amount of m systems before the moment of kT is $u(k-1), u(k-2), \cdots, u(k-m)$. And according to

$$\begin{cases} x(k+1) = Ax(k) + Bu(k-m), \\ y(k) = Cx(k) \end{cases}$$

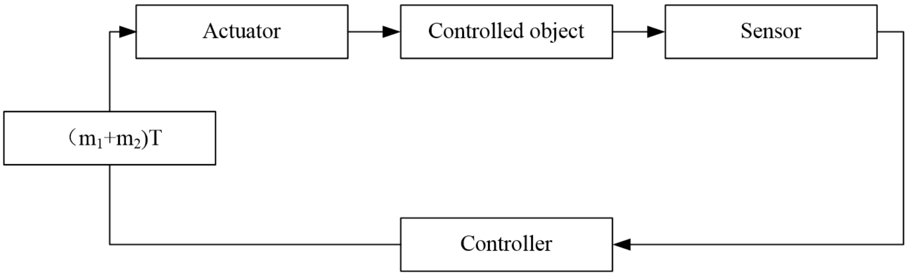

Fig. 1. Equivalent structure diagram of deterministic network remote control system

the system state at the moment of $(k+m)T$ can be predicted as $\overline{x}(k+m)$. Now

$$\begin{aligned}&\overline{x}(k+m)=A\overline{x}(k+m-1)+Bu(k-1)\\&=A\left[A\overline{x}(k+m-2)+Bu(k-2)\right]+Bu(k-1)\\&=A^{m}x(k)+A^{m-1}Bu(k-m)+A^{m-2}Bu(k-m+1)+...+Bu(k-1)\\&=A^{m}x(k)+\textstyle\sum_{i=1}^{m}A^{i-1}Bu(k-i)\,.\end{aligned}$$

And then from the predicted value $\overline{x}(k+m)$ of state, the finite time two-order optimal control law that is the mot matching with the controlled object actually receiving control information at the moment of $(k+m)T$ can be calculated as

$$u(k)=-K\overline{x}(k+m)\ .$$

At that time, the system state feedback gain matrix K is: $K=\left(R+B^{\mathrm{T}}PB\right)^{-1}\cdot B^{\mathrm{T}}PA$. Here, P refers to the positive definite solution of the algebra Riccati equation $P=A^{\mathrm{T}}PA-A^{\mathrm{T}}PB\left(R+B^{\mathrm{T}}PB\right)^{-1}B^{\mathrm{T}}PA+Q$. The corresponding performance indicator of infinite time is

$$J=\sum_{K=0}^{\infty}\left[x(k)^{\mathrm{T}}Qx(k)+u(k)^{\mathrm{T}}Ru(k)\right]\ .$$

2.2. Smith predictive control

The Smith predictive control is to the Smith predictor to compensate the pure delay, and transforms the time-delay system into an equivalent no delay system. When the initial state of the system is zero, the shape of the output response curve of the controlled object after compensation and the response characteristics are exactly the same as those without delay, but only a delay in time. It is supposed that the closed-loop system without delay is the state feedback control, and the system structure is shown in Fig. 2. According to the equivalent structure of network remote control system diagram shown in Fig. 1, a delay link is added before the controlled object in Fig. 2. The system structure diagram of using the Smith prediction control for the compensation is shown in Fig. 3, where the dotted line is the designed Smith predictor. If the model of the controlled object in the Smith predictor is very accurate, Fig. 3 can be further simplified and Fig. 4 is obtained. It can be seen that the Smith predictive control is equivalent to passing a time delay value of the control action in the time coordinate.

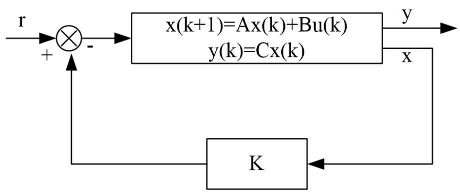

Fig. 2. Structure of closed loop control system without time delay

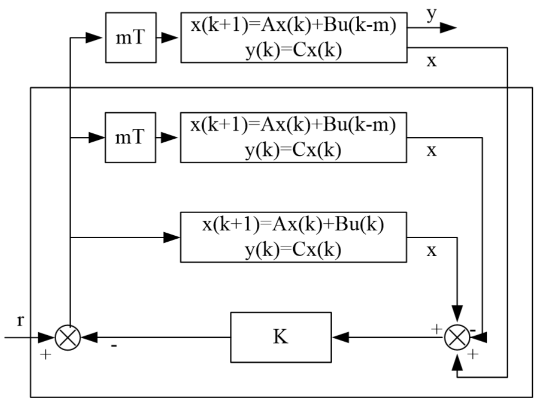

Fig. 3. Structure of network remote control system using Smith predictive control

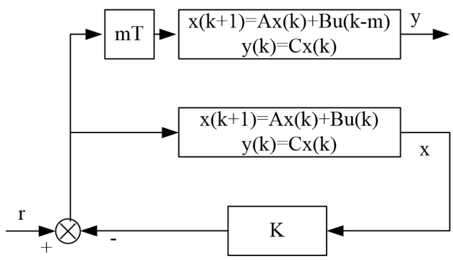

Fig. 4. Equivalent structure diagram of network remote control system using Smith predictive control

2.3. Step change control

The idea of step change control is: first of all, through a system state transformation, the system with delay is transformed into the system without delay. And then, according to the system without delay, the optimal state feedback control law is designed. Finally, through the inverse transformation of the transformation made, the control law of the system with delay is obtained.

The state transformation with control memory is introduced:

$$z(k) = x(k) + \sum_{i=1}^{m} A^{i-m-1} B u(k-i) \; .$$

Then

$$z(k+1) = x(k+1) + \sum_{i=1}^{m} A^{i-m-1} B u(k+1-i) \; .$$

After substituting

$$\left\{ \begin{array}{l} x(k+1) = Ax(k) + Bu(k-m) \\ y(k) = Cx(k) \end{array} \right\} .$$

into the above formula, it can obtained

$$\begin{aligned} & z(k+1) = x(k+1) + \textstyle\sum_{i=1}^{m} A^{i-m-1} B u(k+1-i) \\ & = Ax(k) + Bu(k-m) + \textstyle\sum_{i=1}^{m} A^{i-m-1} B u(k+1-i) \\ & = Ax(k) + A^{-m} B u(k) + \textstyle\sum_{i=1}^{m+1} A^{i-m-1} B u(k+1-i) \\ & = A\left[x(k) + \textstyle\sum_{i=1}^{m} A^{i-m-1} B u(k-i)\right] A^{-m} B u(k) = Az(k) + A^{-m} B u(k) \, . \end{aligned}$$

Let $\overline{B} = A^{-m}B$, then the above formula can be expressed as

$$z(k+1) = Az(k) + \overline{B} u(k) \; .$$

3. Basic idea of deterministic control

In this paper, we mainly study the cases of single data packet transmission and system single loop, without considering the loss of data packets during network transmission. The schematic diagram of the network remote control system with time delay can be shown in Fig. 5. In the figure, τ_{sc} suggests the transmission delay from the sensor nodes to controller nodes, and τ_{ca} refers to the transmission delay from the controller nodes to the actuator nodes. The operation time τ_{c} of the controller itself is generally incorporated into τ_{ca}. The execution time of the controlled object is negligible compared with the network delay. The influence of many factors on the network results in that the network delay τ_{sc} and τ_{ca} have stochastic time-varying characteristic, and the analysis of the system and the design of the controller are faced with great difficulties. The deterministic control theory is used to solve the delay problem in the network remote control system.

Assuming that the delay has boundaries, and $\tau_{\mathrm{sc}} \le m_1 T$, $\tau_{\mathrm{ca}} \le m_2 T$, where m_1 and m_2 are positive integers, and T is the sampling cycle of the system. The sensor, controller, and actuator all choose the working way of time driving, which is the requirements of deterministic control method.

The model for deterministic remote control system is constructed. In the re-

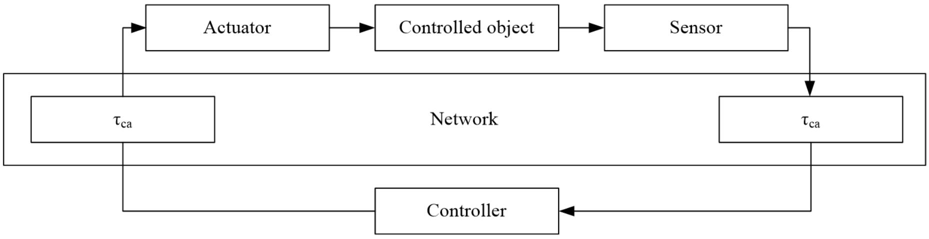

Fig. 5. Structure of network remote control system

ceiving terminal of controller and actuator, a FIFO queue buffer is arranged in the length of m_1T and m_2T, respectively. As a result, the transmission delay between the sensor to the controller is fixed as m_1T, and transmission delay between the controller to the actuator is fixed as m_2T. In this way, the random delay in the network is converted to fixed delay, and the design of the controller is simplified. This approach not only cleverly avoids the uncertainty of network delay, but also ensures the order of receiving information.

Figure 6 shows the closed loop system diagram of this deterministic control. Since the converted time delay is fixed, the controller can be exchanged with the delay section in terms of position, as shown in the upper and bottom parts of Fig. 7. For the controlled systems, the three structures are equivalent.

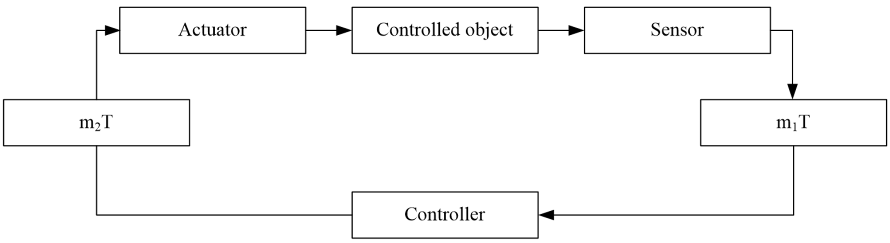

Fig. 6. Structure of deterministic network remote control system

4. Results and discussion

The sampling cycle of the system is $T = 0.05s$, and the discrete state equation of controlled object is:

$$x(k+1) = \begin{bmatrix} 1 & 0.04961 \\ 0 & 0.9843 \end{bmatrix} x(k) + \begin{bmatrix} 0.00014 \\ 0.00571 \end{bmatrix} u(k)\ ,$$

The infinite time two-order performance indicator function is chosen as

$$J = \sum_{K=0}^{\infty} \left[x(k)^T Qx(k) + u(k)^T Ru(k) \right]$$

taking

$$Q = \begin{bmatrix} 50 & 0 \\ 0 & 1 \end{bmatrix},$$

$R = 0.01$, so as to solve the state feedback matrix in the state predictive control $K = [64.1596,\ 32.0961]$ and the state feedback matrix in the step change control $\widetilde{K} = [64.1596,\ 52.3870]$.

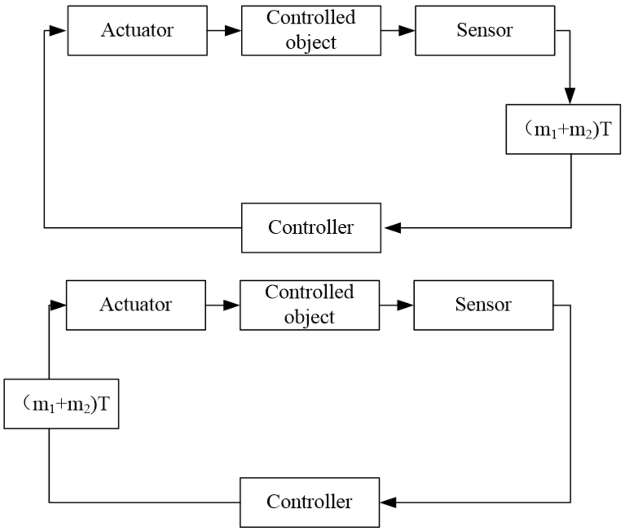

Fig. 7. Equivalent structure diagram of deterministic network remote control system

Assuming that the delays τ_{sc} and τ_{ca} in the network remote control system are randomly changing, and the maximum value is not more than 4 times of T value. Let $m = 8T$, the deterministic control method is adopted [14]. Figure 8 shows the output response curve of the system when the initial state of the controlled object is $[1,\ -2]^{\mathrm{T}}$, and the State Predictive Control and the step change control are adopted, respectively. It can be seen from the simulation results that the two curves coincide completely, and the essential consistency between the state predictive control and the step change control is verified. Figure 9 shows the step response curves of the system under three conditions, namely, the state predictive control, the step change control and the Smith predictive control, when the initial state of the controlled object is zero. The three curves also coincide completely, and the equivalence of the three methods when the initial state of the system is zero is verified. Figure 10 shows the output response curves of the system under three conditions, namely, the state predictive control, the step change control and the Smith predictive control when the initial state of the controlled object is $[1,\ -2]^{\mathrm{T}}$. The results show that, when the initial state of the system is not zero, the control effects of the state predictive control and the step change control are better than the traditional Smith predictive control.

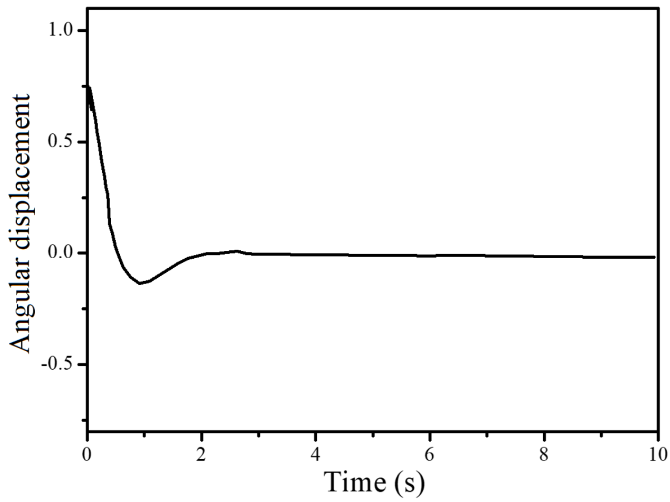

Fig. 8. Output response curves of state predictive control and step change control

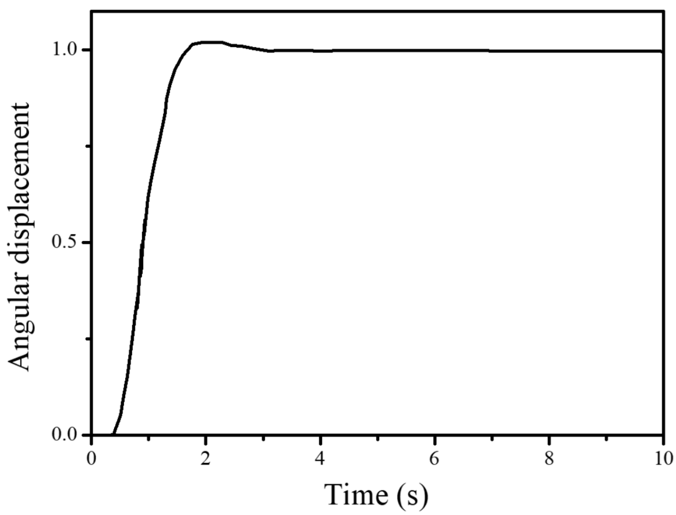

Fig. 9. Output response curves of three control methods when the initial state is zero

5. Conclusion

In this paper, three control methods of deterministic network remote control system are discussed, namely the Smith predictive control, the state predictive control and the step change control. On the basis of research idea of these three methods, through theoretical analysis, the essence consistency of state predictive control and step change control is verified. In addition, the equivalence relation of the two in

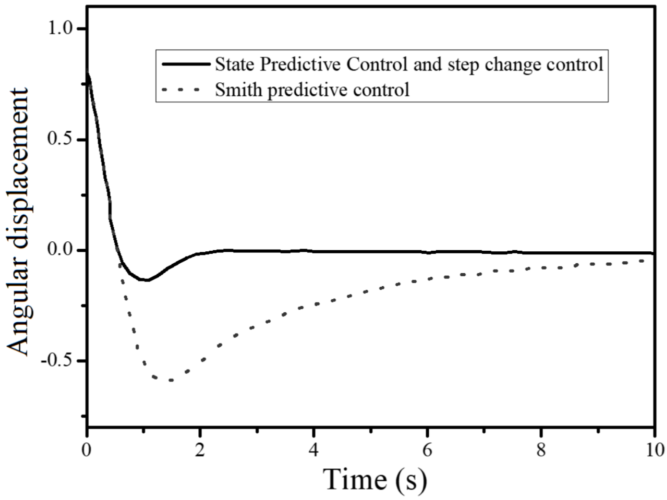

Fig. 10. Output response curves of three control methods when the initial state is not zero

the case of initial state of system of zero with the Smith prediction control. The simulation results verify the correctness of the obtained results.

References

[1] G. Yang, L. Xie, M. Mäntysalo, X. Zhou, Z. Pang, L. D. Xu, S. Kao-Walter, Q. L. Chen, R. Zheng: *A health-iot platform based on the integration of intelligent packaging, unobtrusive bio-sensor, and intelligent medicine box.* IEEE Transactions on Industrial Informatics *10* (2014), No. 4, 2180–2191.

[2] M. A. Harris, K. P. Patten: *Mobile device security considerations for small- and medium-sized enterprise business mobility.* Information Management & Computer Security *22* (2014), No. 1, 97–114.

[3] D. H. Jenkins, J. F. Rappold, J. F. Badloe, O. Berséus, L. Blackbourne, K. H. Brohi, F. K. Butler, A. P. Cap, M. J. Cohen, R. Davenport, M. de Pasquale, H. Doughty, E. Glassberg, T. Hervig, T. J. Hooper, R. Kozar, M. Maegele, E. E. Moore, A. Murdock, P. M. Ness, S. Pati, T. Rasmussen, A. Sailliol, M. A. Schreiber, G. A. Sunde, L. M. van de Watering, K. R. Ward, R. B. Weiskopf, N. J. White, G. Strandenes, P. C. Spinella: *Trauma hemostasis and oxygenation research position paper on remote damage control resuscitation: Definitions, current practice, and knowledge gaps.* Shock *41* (2014), Suppl. No. 1, 3–12.

[4] U. Bodin, K. Wolosz: *Proportional throughput differentiationwith cognitive load-control on WSN channels.* EURASIP Journal on Wireless Communications and Networking (2015), No. 1, paper 186.

[5] T. N. Le, W. L. Chin, H. H. Chen: *Standardization and security for smart grid communications based on cognitive radio technologies—a comprehensive survey.* IEEE Communications Surveys & Tutorials *19* (2017), No. 1, 423–445.

[6] M. Mehmetoglu, E. Akyol, K. Rose: *Deterministic annealing optimization for Witsenhausen's and related decentralized stochastic control problems.* CoRR abs/1607.02893 (2016), arXiv: 1607.02893v1 [cs.SY] 11 Jul 2016.

[7] R. Caballero-Águila, A. Hermoso-Carazo, J. Linares-Pérez: *Optimal state estimation for networked systems with random parameter matrices, correlated noises and delayed measurements.* International Journal of General Systems *44* (2015), No. 2, 142–154.

[8] Z. Zhang, K. Long, J. Wang, F. Dressler: *On swarm intelligence inspired self-organized networking: its bionic mechanisms, designing principles and optimization approaches.* IEEE Communications Surveys & Tutorials *16* (2014), No. 1, 513–537.

[9] S. Huang, B. Liang, J. Li: *Distributed interference and delay aware design for D2D communication in large wireless networks with adaptive interference estimation.* IEEE Transactions on Wireless Communications *16* (2017), No. 6, 3924–3939.

[10] R. Luck, A. Ray: *Experimental verification of a delay compensation algorithm for integrated communication and control systems.* International Journal of Control *59*, (1994), No. 6, 1357–1372.

[11] M. H. Vafaie, B. M. Dehkordi, P. Moallem, A. Kiyoumarsi: *A new predictive direct torque control method for improving both steady-state and transient-state operations of the PMSM.* IEEE Transactions on Power Electronics *31* (2016), No. 5, 3738–3753.

[12] S. Anand, B. G. Fernandes, J. Guerrero: *Distributed control to ensure proportional load sharing and improve voltage regulation in low-voltage DC microgrids.* IEEE Transactions on Power Electronics *28* (2013), No. 4, 1900–1913.

[13] G. A. Papafotiou, G. D. Demetriades, V. G. Agelidis: *Technology readiness assessment of model predictive control in medium-and high-voltage power electronics.* IEEE Transactions on Industrial Electronics *63* (2016), No. 9, 5807–5815.

[14] S. Vaidyanathan, S. Sampath, A. T. Azar: *Global chaos synchronisation of identical chaotic systems via novel sliding mode control method and its application to Zhu system.* International Journal of Modelling, Identification and Control *23* (2015), No. 1, 92–100.

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