Acta Technica 62 (2017), No. 6B, 523–536

Simulation control of position servo system in networked environment

Hongliang Gao[1]

Abstract. The simulation control of position servo system in networked environment is investigated in this paper. The structure, the dynamical model, and the transfer function model of the position servo system are researched. Then the PID discrete controller is designed and critical pieces of code in C++ are presented. In this paper, the simulation platform of NCSs is developed by using network simulation software Truetime, and the simulation model of position servo system in networked environment is established. To show the influence rules of network environment on control effect, four different kinds of networked environments are considered in the simulation study. The tracing performance of the position servo system and the control signal are shown, simulation results illustrate the influence rules of network environment on control effect for position servo system.

Key words. Position servo system, Networked control systems (NCSs), PID discrete controller, Truetime.

1. Introduction

The task of position servo system is to make changes of the system output according to the same law of the input signal, and the error between input and output should be kept within the recommended limits [1–4]. The position servo system is the most widely used in military, such as missile launcher control system, radar antenna control system, artillery pointing control system and so on [5–7]. In other areas, the position servo system is also widely used, for instance, the trajectory control of computerized numerical control machine, the automatic steering device on ship and the screw-down device of rolling machine [8, 9]. In position servo system, the mechanical position or angle is usually regarded as the controlled object. As position command signal frequently changes, and the demand of the position servo system is that the system output can accurately follow the changes of the input signal. The rapidity, flexibility and the accuracy of the output response become the

[1]College of Mechatronics and Control Engineering, Hubei Normal University, Huangshi, Hubei 435002, China

main features of a position servo system. So, the tracing performance is the main dynamic indicator of a position servo system.

Networked control systems (NCSs) are distributed real-time feedback control systems, and the data exchanges among controller, sensor, and actuator is realized by network. In NCSs, information and control signal exchange between distributed devices using serial communication network and the control system has a control loop by using serial communication network [10–12].

NCSs are complex systems involving control, network communication and computer. So the new requirements are put forward for studying NCSs. There are two important characteristics for NCSs, that is, time characteristic and event characteristic. There exists a certain difficulty in simulation research precisely because of its complex features. NCSs are the combination of control system and network transmission system. This means that the simulation of NCSs should take into account characteristics of control system and network transmission system [13, 14].

Position servo system is a widely used system in many areas, but the control problem of position servo system in networked environment has rarely been studied. In this paper, we take the position servo system as a controlled object, build a simulation platform by Truetime, and the influence rules of network environment on control effect is studied by four different cases.

The paper is organized as follows. Section 2 deals with the mathematical model of a position servo system. Section 3 discusses the PID discrete controller design in NCSs. Simulation results of the position servo system in networked environment, which illustrates the influence rules of network environment on control effect in four kinds of cases, are presented in Section 4. Finally, conclusions are given in Section 5.

2. Mathematical model of position servo system

2.1. The dynamical model of position servo system

The position servo system is composed of electric bridge, amplifier, DC servo motor, gear train and load [15], the structure of the system is shown in Figure 1.

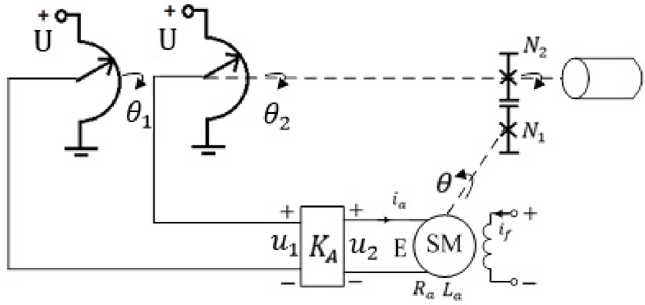

Fig. 1. The structure of position servo system.

First, the differential equations of the system's components should be established. The equations of electric bridge are described as follows:

$$u_1 = K_1(\theta_1 - \theta_2)\,, \tag{1}$$

$$u_1 = K_1(\theta_1 - \theta_2)\,, \tag{2}$$

where, u_1 is the deviation voltage of the electric bridge, in V; K_1 is the gain of the electric bridge; θ_1 is the mechanical angle of the sending machine, in degrees; θ_2 is the mechanical angle of the receiving machine, in degrees; U is the common voltage of the electric bridge, in V; θ is the angle of rotor of the servo motor, in degrees.

The equation of amplifier is

$$u_2 = K_A u_1\,, \tag{3}$$

where, u_2 is the armature voltage, in V; K_A is the gain of the amplifier.

The equations of DC servo motor are given as follows:

$$u_2 = R_a i_a + L_a \frac{di_a}{dt} + E\,, \tag{4}$$

$$E = K\frac{d\theta}{dt} \tag{5}$$

$$M = C_m i_a \tag{6}$$

$$J\frac{d^2\theta}{dt^2} + f\frac{d\theta}{dt} = M\,, \tag{7}$$

where, R_a is the armature resistance, in Ω; i_a is the armature current, in A; L_a is the armature inductance, in mH; E is the back electromotive force (back-EMF) of the armature, in V; K is the back-EMF coefficient; M is the electromagnetic torque of the motor, in N·m; C_m is the torque coefficient of the motor, in N·m/A; J is the moment of inertia of the motor and load converted onto the motor axis, in kg·m^2; f is the viscous friction coefficient of the motor and load converted onto the motor axis, in N·m·s/rad.

The equation of the gear system is given by:

$$\theta_2 = \frac{N_1}{N_2}\theta\,, \tag{8}$$

where, N_1 and N_2 is the number of gear teeth of the big and the small gears separately.

By using Laplace transform in zero initial condition, the equations above are transformed as follows:

From (1), we have

$$U_1(s) = K_1[\theta_1(s) - \theta_2(s)], \tag{9}$$

From (3), we obtain

$$U_2(s) = K_A U_1(s), \tag{10}$$

From (4), (5), (6) and (7), we have

$$U_2(s) = R_a I_a(s) + L_a s I_a(s) + E(s), \tag{11}$$

$$E(s) = K s\theta(s), \tag{12}$$

$$M(s) = C_m I_a(s), \tag{13}$$

$$Js^2\theta(s) + fs\theta(s) = M(s). \tag{14}$$

From (8), we have

$$\theta_2(s) = \frac{N_1}{N_2}\theta(s). \tag{15}$$

According to the transfer relations of each signal, we can obtain the dynamic block diagram of position servo system, as shown in Figure 2.

2.2. Transfer function model of position servo system

By using equivalent transform, and L_a is usually set to 0, we can obtain the transfer function of position servo system based on the signal flow diagram as shown in Figure 2.

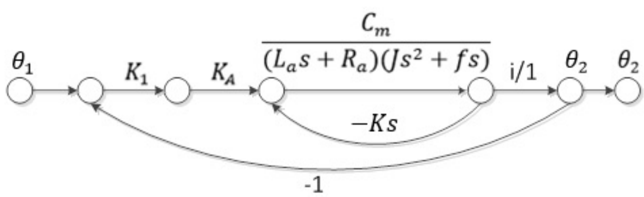

Fig. 2. The signal flow diagram of position servo system.

The transfer function is

$$G(s) = \frac{\theta_2(s)}{\theta_1(s)} = \frac{K_1 K_A C_m/(R_a N_2/N_1)}{Js^2 + (f + C_m K/R_a)\, s + K_1 K_A C_m/(R_a N_2/N_1)}. \tag{16}$$

In this paper, detailed parameters of a position servo system are as follows:
$K = 3$, $f = 0.22$N/m·s, $K_1 = 2$, $K_A = 20$, $\frac{N_2}{N_1} = 0.1$, $C_m = 0.4$N·m/A, $R_a = 7.5\Omega$, $J = 0.006 kg \cdot m^2$.

Based on the parameters above, the transfer function (16) can be transformed as following:

$$G\left(s\right)=\frac{\frac{K_1K_AC_m}{\frac{R_aN_2}{N_1}}}{Js^2+\left(f+\frac{C_mK}{R_a}\right)s+\frac{K_1K_AC_m}{\frac{R_aN_2}{N_1}}}=\frac{3555.5}{s^2+63.333s+3555.5}\,. \tag{17}$$

3. PID discrete controller design in NCSs

The idealized equation of PID controller is

$$U(t)=K_P[e(t)+\frac{1}{T_I}\int_0^t e(t)dt+T_D\frac{de(t)}{dt}] \tag{18}$$

where, $U(t)$ is the output signal of the controller, that is the output control signal of the system; e(t) is the input deviation signal of the controller, it is equal to the difference value between the input value and the measured value; K_P is the proportionality coefficient of the controller; T_I is the integral time of the controller; T_D is the derivation time of the controller.

The formula (18) can be simulated by discrete event system, and implemented by computers. The discretization expression is as follows:

$$U(n)=K_P\{e(n)+\frac{T_S}{T_I}\sum_{K=0}^{n}e(K)+\frac{T_D}{T_S}[e(n)-e(n-1)]\}\,, \tag{19}$$

where, e(n) is the difference value of the nth sampling; $U(n)$ is output control signal of the computer of the nth sampling; T_S is the sampling period.

In this paper, the PID discrete controller is adopted in networked environment. The design of PID discrete controller is as follows.

$$P(k)=K[r(k)-y(k)]\,, \tag{20}$$

$$I(k)=I(k-1)+\frac{Kh}{T_i}[r\left(k\right)-y(k)]\,, \tag{21}$$

$$D(k)=\alpha_d D\left(k-1\right)+b_d[y\left(k-1\right)-y(k)]\,, \tag{22}$$

$$u(k)=P(k)+I(k)+D(k)\,, \tag{23}$$

where, $\alpha_d=\frac{T_d}{Nh+T_d}$, $b_d=\frac{NKT_d}{Nh+T_d}$, K is the proportional coefficient, T_i is integral coefficient, T_d is the differential coefficient, N is the differential gain, h is the sample interval of the sensor.

Based on the algorithm above, some key codes of controller implementation in C++ are as follows.

The initialization codes:

```
data->h = 0.010;
data->K = 0.5;
data->Ti = 0.035;
data->Td = 0.04;
data->N = 100.0;
data->ad = data->Td/(data->N*data->h+data->Td);
data->bd = data->N*data->K*data->ad;
data->yold = 0.0;
data->Dold = 0.0;
data->u = 0.0;
```

The controller codes:

```
P = d->K*(r-y);
I = d->Iold;
D = d->ad*d->Dold + d->bd*(d->yold-y);
d->u = P+I+D;
d->Iold = d->Iold + d->K*d->h/d->Ti*(r-y);
d->Dold = D;
d->yold = y;
```

where, data and d in the program are both the structure data class in C language.

4. Simulation results and analysis

4.1. The establishment of networked system model

In this paper, the simulation platform of NCSs is developed by using network simulation software Truetime 2.0 [16]. The module library of Truetime 2.0 are composed of six modules, these modules are Turetime Kernel, Truetime network, Truetime wireless network, battery module, data getting module and data sending module, where Turetime Kernel and Truetime network are the most basic modules.

Truetime Kernel modules are used as network nodes of the NCSs, which include the converter interface of A/D and D/A, and the schedule interface for displaying the allocation of public resources (CPU, monitor and network) in simulation. In the initialization, the function of the interface of external interrupts and the interface of digital signal receiving and sending can be directly realized by defining the initialization function. The core of the module is the flexible real-time kernel, which includes a number of data structures, such as waiting queues, time queues, thread records, interrupt handlers and timers. The Kernel module works according to tasks defined by the user, the task execution depends on the internal event and external event, which is generated by way of interruption. When the internal and external interrupt occurs, the interrupt processor defined by the user is called to execute the interrupt. The independent computer module function is completely determined by the user, such as the control task and the network interactive task. The execution of the task and the interrupt processor is implemented in code function written by the user, the code is written in MATLAB or C++.

Truetime network modules are used for communication between network nodes, in order to provide communication resource for NCSs, and can be used for the simulation of the media access of local area networks and the transmission of the packets. It includes various network parameters, such as the node number of the networks, transmission rate, and medium access control (MAC) protocol etc., where MAC includes CSMA/CD (e.g. Ethernet), CSMA/CA (e.g. CAN), TDMA (e.g. TTP), FDMA (e.g. TACS) and Round robin (e.g. Token bus). The network module adopts event-driven way, and the network module performs work when there are messages in and out of the network. In TrueTime, a variety of scheduling strategies are predefined, such as Fixed Priority (FP), Rate Monotonic (RM), Deadline Monotonic (DM) and Earliest Deadline First (EDF).

In this study, Turetime Kernel is selected as the controller, the actuator and the sensor shared one Turetime Kernel, the controlled object is the position servo system, the transfer function model is $\frac{3555.5}{s^2+63.333s+3555.5}$. The interference node uses one Turetime Kernel, which generates disturbing network traffic, and the fraction of the network bandwidth can be adjusted. The reference input of the system is square signal, the sampling period is 0.01s [17]. The simulation model of the position servo system in networked environment is shown in Figure 3.

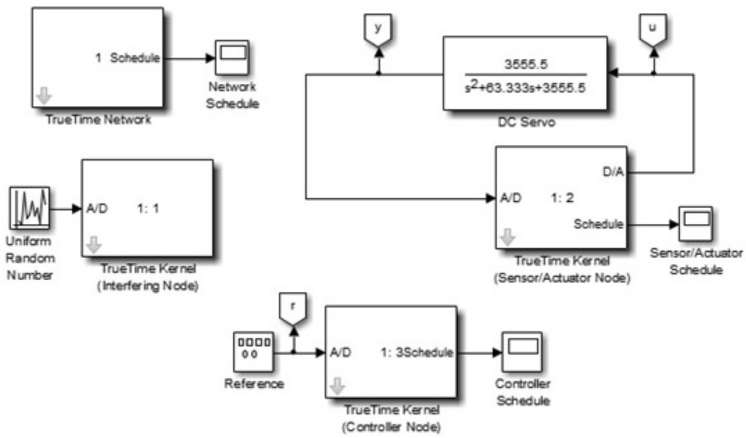

Fig. 3. The simulation model of the position servo system in networked environment.

4.2. Case studies

To show the influence rules of network environment on control effect, four different kinds of networked environments are considered in the simulation study. In four different kinds of networked environments, the fraction of the network bandwidth of the interference node, the loss probability of the network, and network type are considered. The tracing performance of the position servo system and the change of the control signal are shown in this section.

Case 1: The network type is set as CSMA/CD (Ethernet), and the fraction of the network bandwidth of the interference node is set to 0.1, the loss probability of the network is set to 0.1. The output response of the system is show in Figure 4, and the control signal is shown in Figure 5.

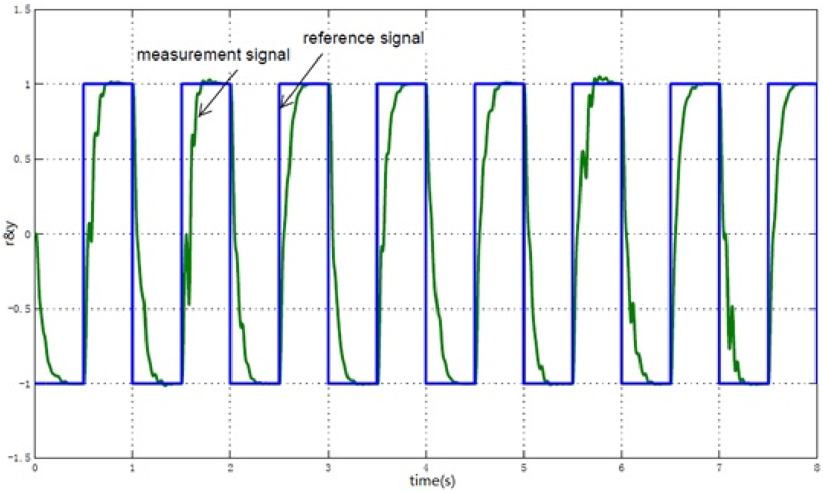

Fig. 4. The output response of the system in case 1.

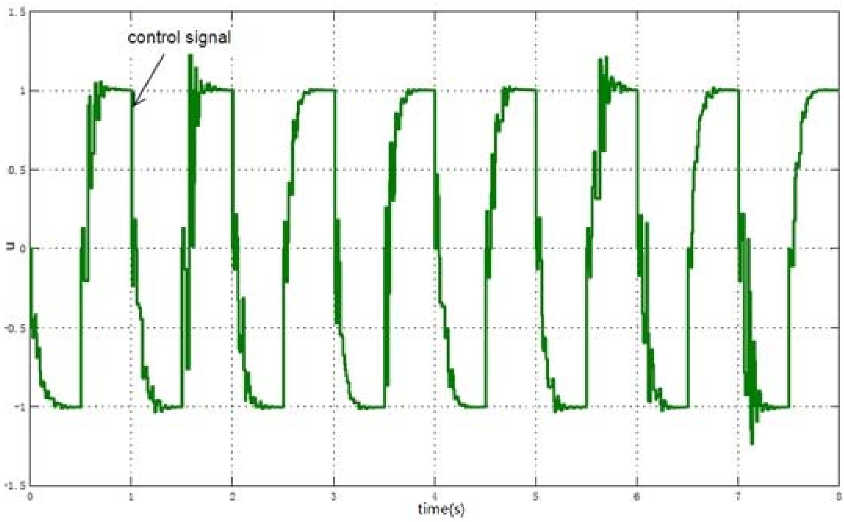

Fig. 5. The control signal of the system in case 1.

Case 2: The network type is set as CSMA/CD (Ethernet), and the fraction of the network bandwidth of the interference node is set to 0.32, the loss probability of the network is set to 0.1. The output response of the system is show in Figure 6, and the control signal is shown in Figure 7.

Case 3: The network type is set as CSMA/CD (Ethernet), and the fraction of the network bandwidth of the interference node is set to 0.1, the loss probability of

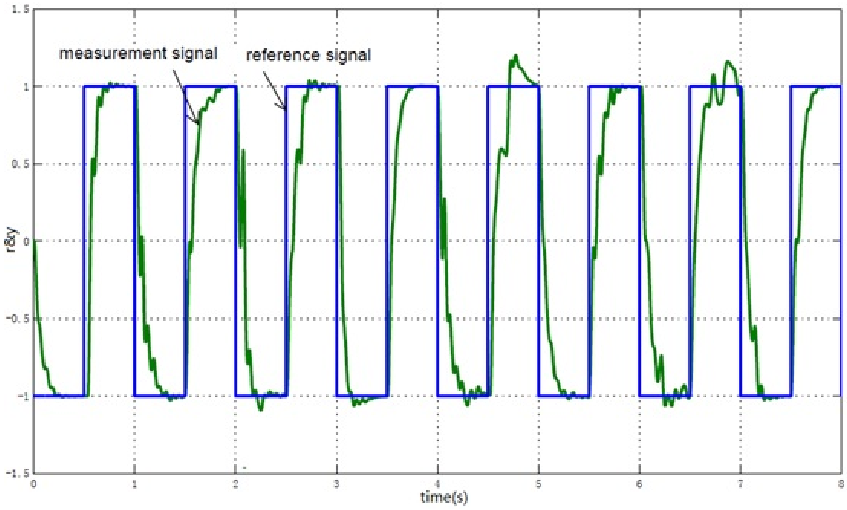

Fig. 6. The output response of the system in case 2.

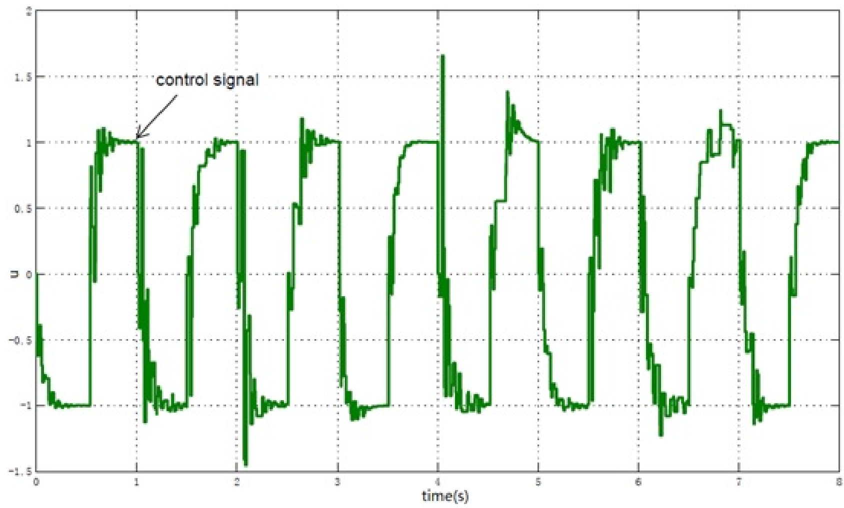

Fig. 7. The control signal of the system in case 2.

the network is set to 0.3. The output response of the system is show in Figure 8, and the control signal is shown in Figure 9.

Case 4: The network type is set as CSMA/AMP (CAN), and the fraction of the network bandwidth of the interference node is set to 0.32, the loss probability of the network is set to 0.1. The output response of the system is show in Figure 10, and the control signal is shown in Figure 11.

From the simulation results above, we can get some important rules for position servo system in networked environment, it includes: 1) In the same network type and the same loss probability of network, the larger of the fraction of network bandwidth

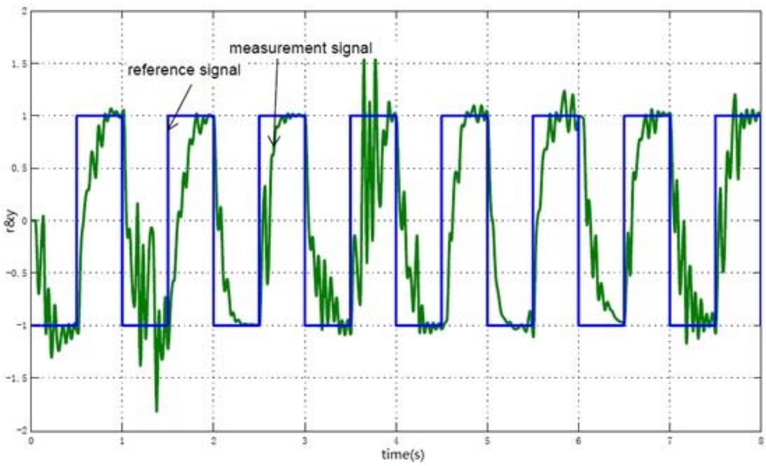

Fig. 8. The output response of the system in case 3.

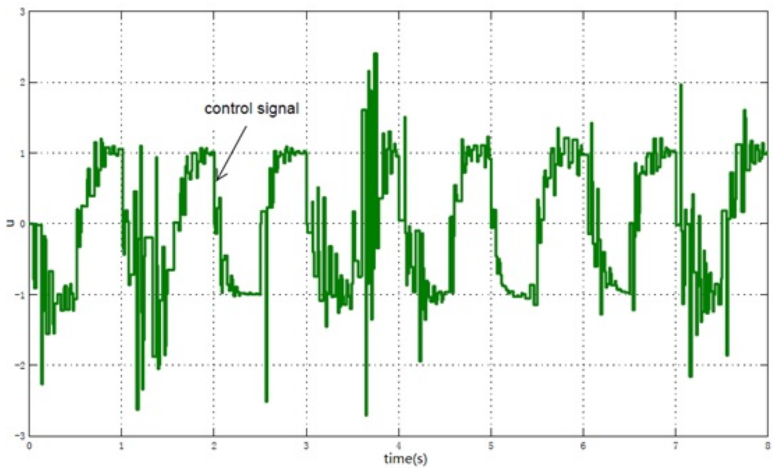

Fig. 9. The control signal of the system in case 3.

of the interference node is, the lower the control effect is, as shown in case 1 (Figure 4 and Figure 5) and case 2 (Figure 6 and Figure 7). 2) In the same network type and the same fraction of network bandwidth of the interference node, the larger of loss probability of the network is, the lower the control effect is, as shown in case 1 (Figure 4 and Figure 5) and case 3(Figure 8 and Figure 9). 3) In the same network type, relative to the fraction of network bandwidth of the interference node, loss probability of the network plays a more significant role for the control performance of the position servo system, as shown in case 2 (Figure 6 and Figure 7) and case 3(Figure 8 and Figure 9). 4) In the same loss probability of the network and the same fraction of network bandwidth of the interference node, the control effect of CAN network is better than Ethernet for position servo system, as shown in case 2

(Figure 6 and Figure 7) and case 4 (Figure 10 and Figure 11).

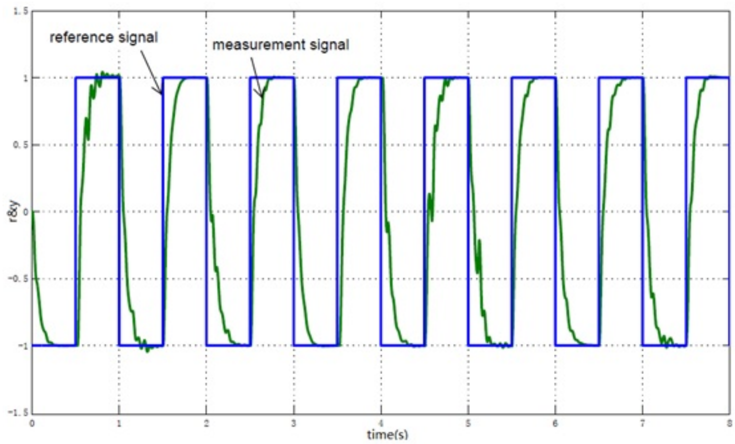

Fig. 10. The output response of the system in case 4.

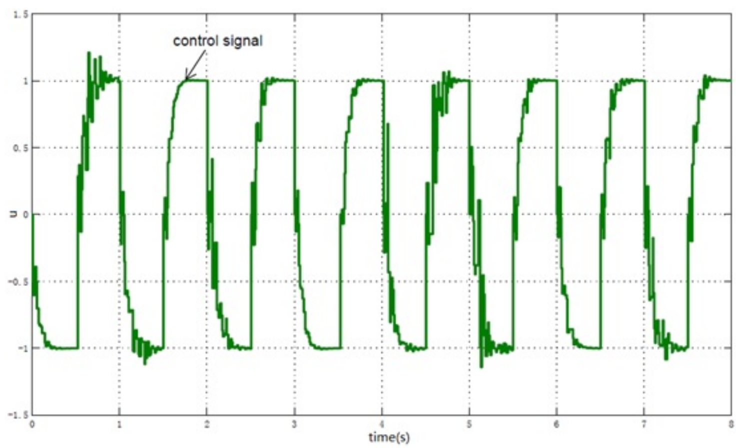

Fig. 11. The control signal of the system in case 4.

5. Conclusions

The simulation control of position servo system in networked environment is studied in this study. First, the mathematical model of position servo system is established, the dynamical model and transfer function model are studied in the process. Then the PID discrete controller in NCSs is designed, the algorithm and program implementation is studied in detail. At last, the simulation model of the position servo system in networked environment is established, and four cases considered different kinds of networked environments are studied. The simulation results illustrate the influence rules of network environment on control effect for position servo system.

In this paper, we consider the network type, loss probability of the network and the fraction of the network bandwidth of the interference node. However, in NCSs, the network delay also exists. Thus, it is interesting and important to consider the network delay in position servo system in networked environment. This issue will be investigated in future research works.

Acknowledgement

This study is supported by the science and technology research program key project of Hubei Provincial Department of Education under Grant No. D20162503 and the Natural Science Foundation of Hubei Province under Grant No. 2016CFC735.

References

[1] Li Baoren, Li Zhuangyun, Xu Yaoming: (1997) Study on adaptive control for a pneumatic position servo system, Advances in Modelling and Analysis C, vol. 49, no. 2, pp. 21-28.

[2] Zheng Jianming, Xiao Min, Yang Mingshun, Li Yan, Kong Lingfei: (2013) Simulation of BPPID control for electrohydraulic proportional position servo system, International Journal of Online Engineering, vol. 9, no. 3, pp. 40-44.

[3] Tivay Ali, Zareinejad Mohammad, Rezaei S. Mehdi, Baghestan Keivan: (2014), A switched energy saving position controller for variable-pressure electro-hydraulic servo systems, ISA Transactions, vol. 53, no. 4, pp. 1297-1306.

[4] Ha Donghyun, Kim Rae-Young, Hyun Dongseok: (2015) Internal-model-principle-based robust optimal nonlinear control for position tracking of permanent-magnet synchronous motor servo system, Transactions of the Institute of Measurement and Control, vol. 37, no. 3, pp. 372-381.

[5] Zhao Xiuping: (2002) Design of a variable-structure controller for the missile launcher servo system, Systems Engineering and Electronics, vol. 24, no. 2, pp. 25-30.

[6] Zhang Qian, Wang Qunjing, Li Guoli, Liu Guohua: (2014) Identification of switched Hammerstein model for radar antenna servo system using the RLS-PSO algorithm, Journal of Computational Information Systems, vol. 10, no. 3, pp. 1077-1084.

[7] Raghavan S.V., Satyanarayana T.: (1983) Microprocessor-Based digital controller for antenna pointing systems, IETE Journal of Research, vol. 29, no. 2, pp. 57-61.

[8] Wei Xile, Wang Jiang, Yang Zhaoxuan: (2006) Smooth-trajectory servo control and implementation for permanent-magnet synchronous motor, Control Theory and Applications, vol. 23, no. 2, pp. 209-216.

[9] Meng Deyuan, Tao Guoliang, Zhu Xiaocong, Ban Wei, Qian Pengfei: (2013) Motion trajectory tracking control of pneumatic position servo systems, Transactions of the Chinese Society for Agricultural Machinery, vol. 44, no. 4, pp. 268-274.

[10] Kim Won-Jong, Ji Kun, Ambike Ajit: (2006), Real-Time operating environment for networked control systems, IEEE Transactions on Automation Science and Engineering, vol. 3, no. 3, pp. 287-296.

[11] Du Shengli, Sun Ximing, Wang Wei: (2014) Guaranteed cost control for uncertain networked control systems with predictive scheme, IEEE Transactions on Automation Science and Engineering, vol. 11, no. 3, pp. 740-748.

[12] Zhan Xisheng, Guan Zhihong, Zhang Xianhe, Yuan Fushun: (2014) Optimal performance of networked control systems over limited communication channels, Transactions of the Institute of Measurement and Control, vol. 36, no. 5, pp. 637-643.

[13] Xisheng Zhan, Zhihong Guan, Xianhe Zhang, Fushun Yuan: (2014) Best tracking performance of networked control systems based on communication constraints, Asian Journal of Control, vol. 16, no. 4, pp. 1155-1163.

[14] Xisheng Zhan, Zhihong Guan, Tao Jiang: (2015) Performance limitation of networked systems with network-induced delay and packet-dropout constraints, Asian Journal of Control, 2015, vol. 17, no. 6, pp. 2452-2459.

[15] Cheng Peng: (2003) Principle of automatic control, Higher Education Press, Beijing.

[16] Anton Cervin, Dan Henriksson, Martin Ohlin: (2010) TRUETIME 2.0 beta reference manual, Department of Automatic Control, Lund University.

[17] Zreikat, Aymen Issa: (2013) QoS-Based Performance and Resource Management in 3G Wireless Networks in Realistic Environments, International Arab Journal of Information Technology, vol. 10, no. 1, pp. 1-9.

Received May 7, 2017