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선형 시스템의 이중 네트워크 제어

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Double Network Control of Linear Systems

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Abstract - In this paper, we propose a double network control approach for linear systems. Generally, there are two network control system structures: the direct structure and the hierarchical structure. Here, the hierarchical structure consists of a main controller and a remote controller. The network delay of the structure only appears in the closed loop between the main controller and the remote system. However, the delay can exist between the remote controller and the actuator. Therefore, we design the double network system with delays between the main controller and the remote system, and the remote controller and the actuator. Finally, we carry out simulations on the linear system to illustrate the effectiveness of the proposed control method.

1. Introduction

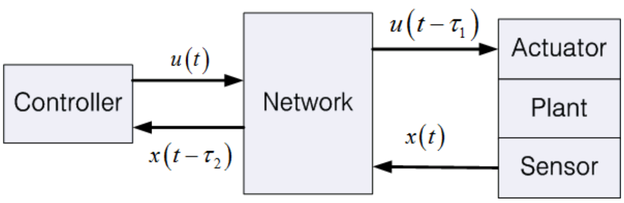
The network control systems (NCSs) have been studied by many researchers over a long period of time [1]-[5]. The NCSs have many benefits such as the ability for remote data transmission and exchange among users, the reduction of the complexity in wiring connections and the costs of medias, and the ease of maintenance [1]. Thus, NCSs are used for applying networks in remote industrial control purposes and factory automation. However, we must solve the delay problems to use the NCSs.

In general, there are two structure in NCS, such as the direct structure and the hierarchical structure. In the direct structure, delays are generated between the controller and the actuator or the sensor, directly [2],[3]. On the other hand, the NCSs have delays originated between the remote controller and the actuator [4],[5]. That is, the main controller transmits the reference signal in a frame or a packet via a network to the remote system and receives the sensor measurement for networked closed-loop control. Here, all delays generated in the remote system are ignored. However, the delay can exist between the remote controller and the actuator.

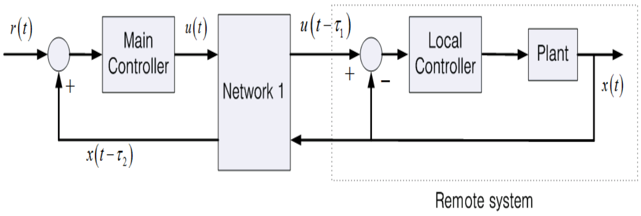
In this paper, we propose a double network control system whose delays are generated between the main controller and the remote system, and the remote controller and the actuator. In addition, We carry out computer simulations on the linear system to verify the effectiveness of the proposed controller.

2. Structure of Network Control Systems

The direct structure of network control systems is consists of a controller and a remote system including a plant, sensors and actuators as depicted in Fig. 1. Here, u is a control input, τ_1 and τ_2 are delays between the controller and the actuator and between the sensor and the controller, respectively.



<Fig. 1> The direct structure



<Fig. 2> The hierarchical structure

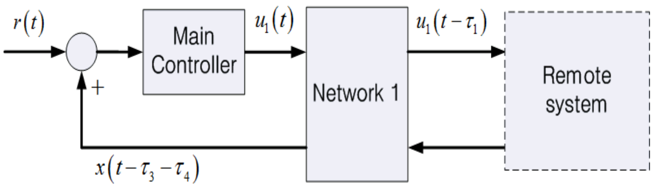
The hierarchical structure of network control systems is composed of a main controller and a remote closed loop system as shown in Fig. 2. The main controller computes and sends the reference signal in a frame or a packet via network to the remote system. The remote system then processes the reference signal to perform local closed-loop control and returns the sensor measurement to a main controller for networked closed-loop control. Here, u is a control input. In addition, τ_1 and τ_2 are transmitted and received delay between the main controller and the remote system, respectively.

3. Double Network Control Systems

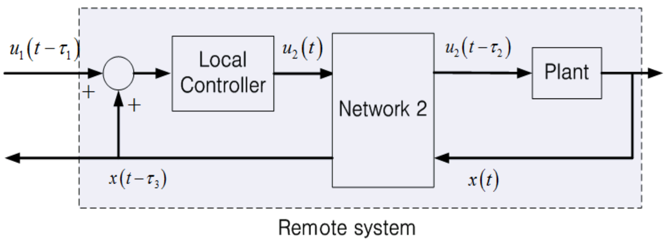
In this section, we design the double network control system with delays between the main controller and the remote system, and the remote controller and the actuator. Although, general hierarchical structure is not considered all delays in remote system, the delays in remote system are in need of being considered. Thus, the controller of the main system and the remote system are designed as double network control system. The double network control systems are illustrated in Figs. 3 and 4.

Consider the linear system as follows:

$$\dot{x}(t)=Ax(t)+Bu_2(t)+A_d x(t-\tau_3)+B_d u_2(t-\tau_2), \qquad (1)$$



<Fig. 3> The double network control system: part 1



<Fig. 4> The double network control system: part 2

where u_2 is the remote control input, τ_2 is the delay between the local controller and the plant, and τ_3 is the output delay in the remote systems.

Here, the remote control input is designed as follows:

$$u_2(t) = -K_2(u_1(t-\tau_1) + x(t-\tau_3)), \tag{2}$$

where K_2 is remote control gain and τ_1 is the delay between the main controller and the remote system.

Using the controller (2), the system (1) is rewritten as follows:

$$\begin{aligned}\dot{x}(t) &= Ax(t) + Bu_2(t) + A_d x(t-\tau_3) + B_d u_2(t-\tau_2) \\ &= Ax(t) - BK_2 x(t-\tau_3) - BK_2 u_1(t-\tau_1) + A_d x(t-\tau_3) \\ &\quad - B_d K_2 x(t-\tau_2-\tau_3) - B_d K_2 u_1(t-\tau_1-\tau_2) \\ &= Ax(t) + \sum_{i=1}^{2} A_i x(t-d_i) + \sum_{i=1}^{2} B_i u_1(t-h_i),\end{aligned} \tag{3}$$

where $A_1 = A_d - BK_2$, $A_2 = -B_d K_2$, $B_1 = -BK_2$, $B_2 = -B_d K_2$, $d_1 = \tau_3$, $d_2 = \tau_2 + \tau_3$, $h_1 = \tau_1$ and $h_2 = \tau_1 + \tau_2$.

Here, the main control input is designed as follows:

$$u_1(t) = -K_1(r(t) + x(t-\tau_3-\tau_4)), \tag{4}$$

where K_1 is the main control gain and τ_4 is the delay between the remote system and the main controller. In addition, $r(t)$ is the reference signal.

Using the controller (4), the system (3) is rewritten as follows:

$$\begin{aligned}\dot{x}(t) &= Ax(t) + \sum_{i=1}^{2} A_i x(t-d_i) + \sum_{i=1}^{2} B_i u_1(t-h_i) \\ &= Ax(t) + \sum_{i=1}^{2} A_i x(t-d_i) \\ &\quad - \sum_{i=1}^{2} B_i K_i (x(t-\tau_3-\tau_4-h_i) + r(t-h_i)) \\ &= Ax(t) + \sum_{i=1}^{4} C_i x(t-t_i) - B_i K_i r(t-h_i),\end{aligned} \tag{5}$$

where $C_1 = A_1$, $C_2 = A_2$, $C_3 = -B_1 K_1$, $C_4 = -B_2 K_1$, $t_1 = d_1$, $t_2 = d_2$, $t_3 = h_1 + \tau_3 + \tau_4$ and $t_4 = h_2 + \tau_3 + \tau_4$.

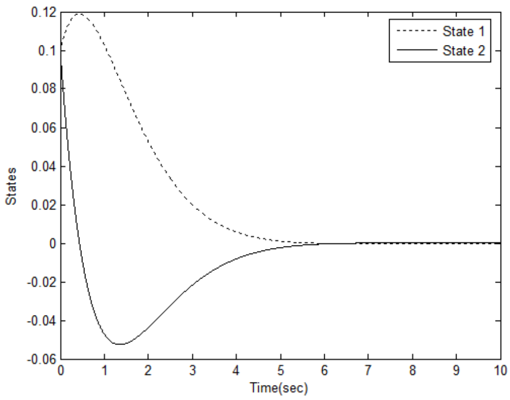
4. Simulation Results

In this section, we apply the proposed control scheme to basic linear system as follows [6]:

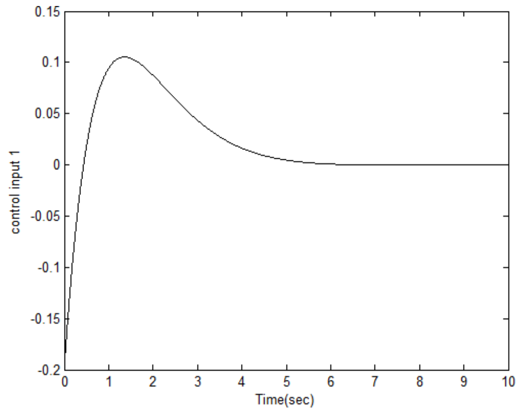
$$\dot{x}(t) = Ax(t) + Bu_2(t) + A_d x(t-\tau_3) + B_d u_2(t-\tau_2), \tag{6}$$

where $A = \begin{bmatrix} 0 & 1 \\ -1.25 & -3 \end{bmatrix}$, $B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$, $A_d = \vec{0}$, $B_d = \vec{0}$. In addition, the time delays are chosen as $\tau_1 = \tau_2 = \tau_3 = \tau_4 = 1$ and the main and remote control gains are 2 and 1, respectively.

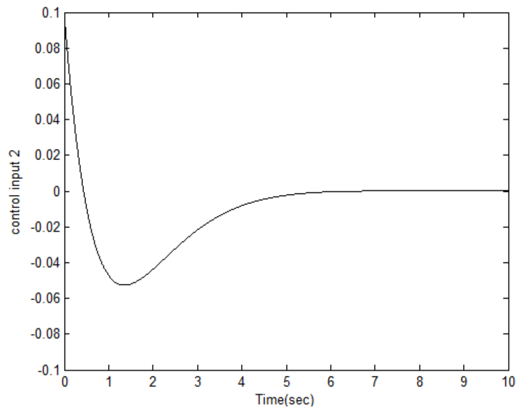
The state trajectories of the closed loop system are shown in Fig. 5. The trajectories are seem that the linear system is stable. In addition, Figs. 6 and 7 show the main and remote control input, respectively.



<Fig. 5> The state trajectories



<Fig. 6> Main control input



<Fig. 7> Remote control input

3. Conclusion

In this paper, we have proposed a double network control method for linear systems. The double network control system is used to control the general system with delays which are existed between the main controller and the remote system, and the remote controller and the actuator. That is, in a general hierarchical structure, it is assumed that all delays generated in the remote system are ignored. Thus, we propose the double network control system whose delays are generated between the main controller and the remote system, and the remote controller and the actuator. In addition, Finally, the proposed controller has been applied the linear system. From the computer simulation results, we show the efficiency of the proposed control approach.

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