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Haptic Communication Based on Environmental Impedance Transmission

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1 Introduction

A bilateral control system has been developed as a method to transmit tactile sense. It enables a human operator to feel as if he/she was really touching the remote environment. Teleoperation with the bilateral control has a wide range of application such as telesurgery, deep-sea operation, space mission, etc. However, the presence of communication delay between a master robot and a slave robot degrades performance and stability[1].

On the other hand, haptic communication systems have been attracting attention as third media following visual and audio communication systems. However, while basic technologies which transmit visual and audio information over the network are established currently, the way of transmitting haptic information to many people is not established yet. If the photographic image is broadcasted with the haptic information, we are able to feel more reality than without the haptic information[2].

In this research, a novel bilateral control system is proposed in order to acquire better performance in the time-delay system at first. In the proposed bilateral control system, an operator is able to manipulate the master robot smoothly and to feel the hard environment even if there exists the communication delay. Secondly, a novel control system which is able to broadcast the haptic information to remote operators called 'audience' is proposed. Each audience is able to feel the remote environment through each actuator without the effect of the other operators' motion. The validity of the proposed control systems is confirmed by experiments.

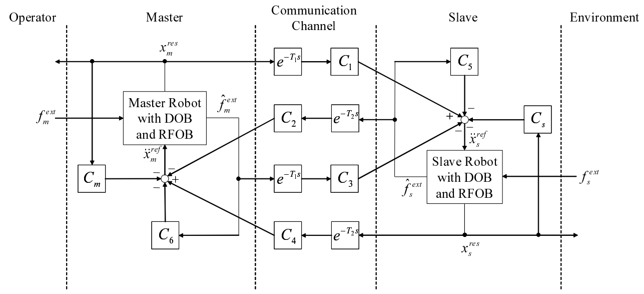

Fig. 1: Block diagram of general four-channel control architecture with time delay

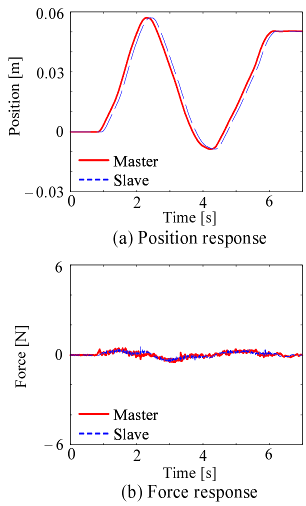

Fig. 2: Free motion

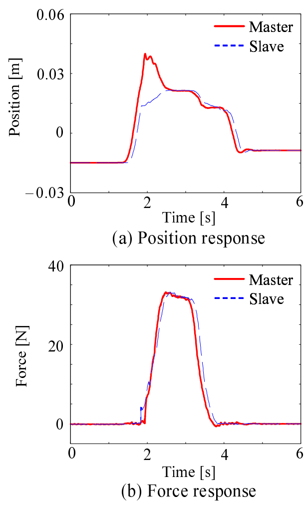

Fig. 3: Contact motion

2 Proposed bilateral control system

2.1 Control system design

Fig. 1 shows a block diagram of general four-channel control architecture with a disturbance observer (DOB) and a reaction force observer (RFOB), where T_1 is delay time from the master robot to the slave robot, and T_2 is delay time from the slave robot to the master robot. $\ddot{x}^{ref}$, x^{res}, f^{ext} and $\hat{f}^{ext}$ denote acceleration reference, position response, external force exerted to the robot and estimated external force, respectively. Subscript m and s denote values of the master robot and that of the slave robot, respectively. In the proposed bilateral control system with time delay, the control parameters C_1, C_2, C_3, C_4, C_5, C_6, C_m and C_s in Fig. 1 are set as

$$C_1 = C_s = C_p \tag{1}$$

$$C_2 = C_3 = C_5 = C_6 = C_f \tag{2}$$

$$C_4 = C_m = C_f C_{z_e} \tag{3}$$

$$C_{z_e} = \hat{k}_e + 2\sqrt{\hat{k}_e} s \tag{4}$$

where C_p is a position controller, and C_f is a force controller. $\hat{k}_e$ is the environmental stiffness which is estimated by using the position and force of the slave robot. In this research, a recursive least-squares method with a forgetting factor is adopted as the estimation algorithm in experiment. Acceleration reference of the proposed control system is represented as follows:

$$\ddot{x}_m^{ref} = C_f C_{z_e}(x_s^{res} e^{-T_2 s} - x_m^{res}) - C_f(\hat{f}_m^{ext} + \hat{f}_s^{ext} e^{-T_2 s}) \tag{5}$$

$$\ddot{x}_s^{ref} = C_p(x_m^{res} e^{-T_1 s} - x_s^{res}) - C_f(\hat{f}_m^{ext} e^{-T_1 s} + \hat{f}_s^{ext}). \tag{6}$$

2.2 Experiment

Virtual constant communication time delay ($T_1 = T_2 = 0.1$[s]) was inserted into communication channels. Fig. 2 shows experimental results of free motion in the proposed bilateral control system. It can be seen that the operator was able to manipulate the master robot smoothly without feeling unnecessary force.

Fig. 3 illustrates experimental results of contact motion. It turns out that stable contact was achieved and the operator was able to feel the hard environment.

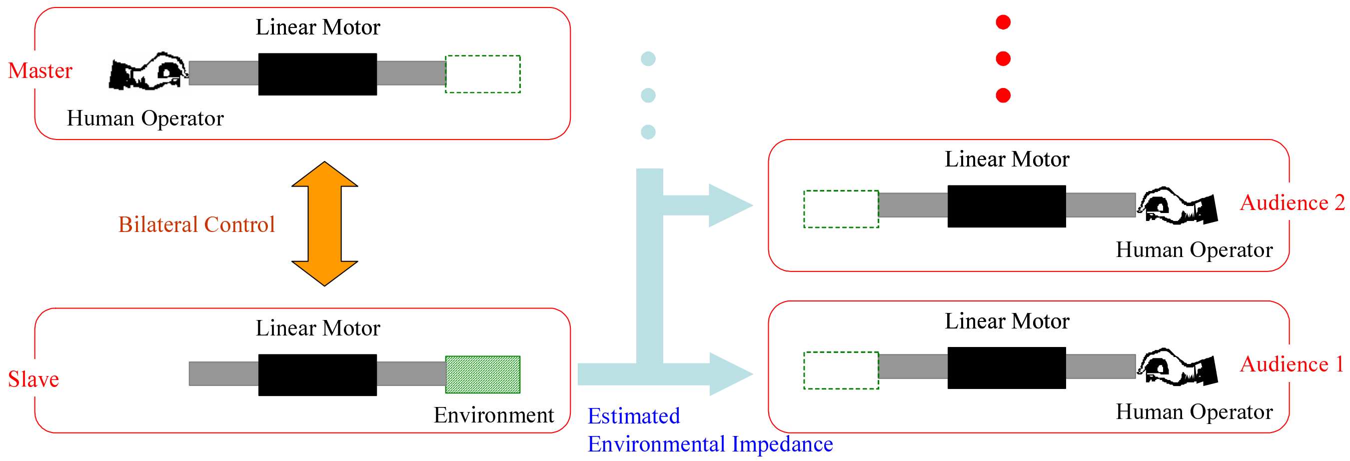

Fig. 4: Overview of the proposed haptic broadcasting system

3 Haptic broadcasting system

3.1 Control architecture

An overview of the proposed haptic broadcasting system is illustrated in Fig. 4. The proposed haptic broadcasting system consists of a master-slave system and multiple actuators which are used for audience to feel environmental impedance. The master-slave system implements the bilateral control. An operator manipulates the master robot. In the slave side, the environmental impedance is estimated by using the position, velocity and force information of the slave robot in real time. Estimated environmental impedance is transmitted over the network to each actuator which is manipulated by each audience in the remote place. Each audience is able to feel the remote environment through each actuator.

Subsequently, the proposed control system implemented in each actuator for audience is described. Acceleration reference $\ddot{x}_i^{ref}$ is provided by

$$\ddot{x}_i^{ref}(t) = \hat{z}_e(t - T_i)C_f\{x_i^{con} - x_i^{res}(t)\} - C_f \hat{f}_i^{ext}(t). \quad (7)$$

Where subscript i is the number of the actuator manipulated by each audience. $\hat{z}_e(t - T_i)$ denotes the estimated environmental impedance transmitted from the slave robot to each audience with time delay T_i. x_i^{res} and $\hat{f}_i^{ext}$ mean an actuator position and force added to the actuator by the audience, respectively. x_i^{con} is a position of the actuator at the time when the actuator received the information that the slave robot contacted with the environment. x_i^{con} is constant while the slave robot is contacting with the environment.

3.2 Experiment

Fig. 5 illustrates the experimental results in the proposed haptic broadcasting system. Virtual constant communication time delay was inserted into communication channels. T_1 is 0.5[s] and T_2 is 1.0[s]. Each audience in the remote place was able to feel about the same impedance as the operator of the master robot felt while the slave robot was contacting with the environment. T_i after the slave robot moved apart from the environment, each audience was able to manipulate each actuator smoothly.

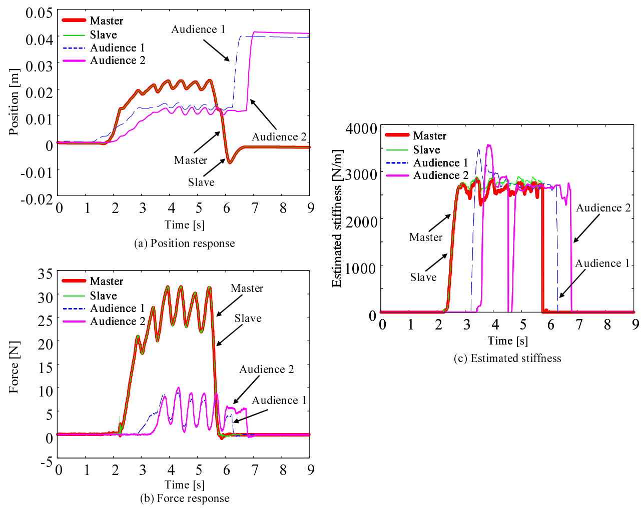

Fig. 5: Experimental result in the haptic broadcasting system

4 Conclusion

The novel bilateral control system with time delay and the haptic broadcasting system were proposed. In the proposed bilateral control system, the operator was able to manipulate the master robot smoothly in the free motion and to feel the hard environment in the contact motion. In the haptic broadcasting system, the multiple operators were able to feel the remote environment. The validity of the proposed control systems was confirmed by the experiments.

References

[1] R. J. Anderson and M. W. Spong, "Bilateral Control of Teleoperators with Time Delay," *IEEE Transactions on Automatic Control*, Vol. 34, No. 5, pp. 494–501, 1989.

[2] Cha Jongeun, Ho Yo-Sung, Kim Yeongmi, Ryu Jeha and I. Oakley, "A Framework for Haptic Broadcasting," *IEEE Multimedia*, Vol. 16, pp. 16–27, 2009.