Comparison of Stabilization Control in Cooperation between Remote Robot Systems with Force Feedback

Eijiro Taguchi[1], Yutaka Ishibashi[1], Pingguo Huang[2], and Yuichiro Tateiwa[1]

[1]Nagoya Institute of Technology, [2]Seijoh University

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Outline

- ✓ Background
- ✓ Purpose
- ✓ Remote robot systems with force feedback
- ✓ Stabilization control
- ✓ Experiment method
- ✓ Experiment results
- ✓ Conclusion and future work

Background

- Remote robot systems with force feedback have been actively researched.
- It is possible to transmit the information about the shape, weight, and softness of a remote object by using haptic interface devices.

The efficiency and accuracy of work can largely be improved.

Transmission of haptic sense over the Internet which does not guarantee QoS (Quality of Service)

Network delay, delay jitter, and packet loss →

- QoE (Quality of Experience) degradation
- Instability phenomena

↓

QoS control and stabilization control

Purpose (1/3)

*1 Q. Qian *et al.*, IEICE Technical Report, CQ2018-27, May/June 2018.
*2 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.
*3 T. Rikiishi *et al.*, IEICE, BS-7-21, Sep. 2017.
*4 P. Huang *et al.*, IEICE, CQ2017-79, Nov. 2017.

Previous Work

By using a remote robot system with force feedback, we compared following three types of stabilization control for work of pushing balls which have different softness[*1].

- ✓ **Reaction force control upon hitting[*2]**
- ✓ **Stabilization control by viscosity[*23]**
- ✓ **Stabilization control with filters[*4]**

➡ **Most effective stabilization control depends on softness.**

Purpose (2/3)

Previous Work

*5 E. Taguchi *et al.*, IEICE General Conference, B-11-17, Mar. 2018.

By using the two systems, we investigate the influence of the network delay on the work of moving one object cooperatively while feeling the reaction force[*5].

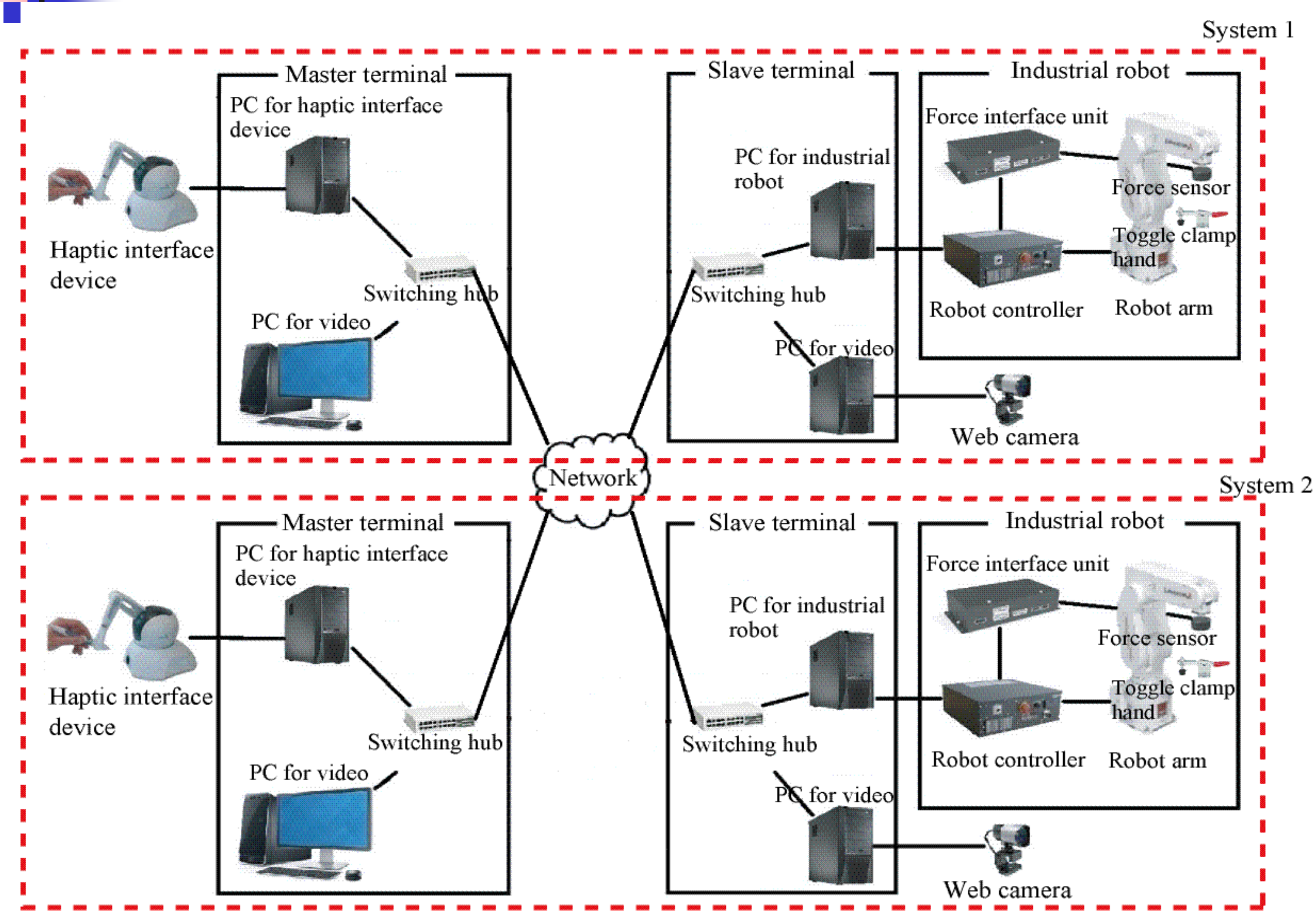
➡ **As the network delay increases, the average work time becomes longer and the instability phenomenon of the system occurs more frequently.**

Purpose (3/3)

This study

- **We apply the three types of stabilization control (reaction force control upon hitting, stabilization control by viscosity, and stabilization control with filters) to the cooperative work of the two systems.**
- **We investigate which types of stabilization control is the most effective by experiment.**

Remote robot systems with force feedback



Calculation method of position

(No stabilization control)

Position of robot

$$\boldsymbol{S}_t = \begin{cases} \boldsymbol{M}_{t-1} + \boldsymbol{V}_{t-1} & (|\boldsymbol{V}_{t-1}| \leq V_{\max}) \\ \boldsymbol{M}_{t-1} + V_{\max}\dfrac{\boldsymbol{V}_{t-1}}{|\boldsymbol{V}_{t-1}|} & (\text{otherwise}) \end{cases}$$

$\boldsymbol{S}_t$: Position vector of industrial robot at time t $(t \geq 1)$

$\boldsymbol{M}_t$: Position vector of haptic interface device at time t

$\boldsymbol{V}_t$: Velocity vector of industrial robot

$V_{\max}$: Maximum velocity of industrial robot (5mm/s)

Calculation method of force

(No stabilization control)

Force outputted at master terminal

$$\boldsymbol{F}_t^{(\mathrm{m})} = K_{\mathrm{scale}}\, \boldsymbol{F}_{t-1}^{(\mathrm{s})}$$

$\boldsymbol{F}_t^{(\mathrm{m})}$: Reaction force outputted at the master terminal at time t

$\boldsymbol{F}_t^{(\mathrm{s})}$: Force received at the master terminal from the slave terminal at time t

K_{scale} : Force scale which changes $\boldsymbol{F}_{t-1}^{(\mathrm{s})}$

Reaction force control upon hitting

Position of robot

Same as no stabilization control

Force outputted at master terminal

$$\boldsymbol{F}_t^{(\mathrm{m})} = \begin{cases} K_{\mathrm{scale}}(\boldsymbol{F}_{t-1}^{(\mathrm{m})} + K_i \boldsymbol{F}_{\mathrm{th}}) & (|\boldsymbol{F}_{t-1}^{(\mathrm{m})} - K_{\mathrm{scale}}\, \boldsymbol{F}_{t-1}^{(\mathrm{s})}| > |\boldsymbol{F}_{\mathrm{th}}|) \\ K_{\mathrm{scale}}\, \boldsymbol{F}_{t-1}^{(\mathrm{s})} & (\text{otherwise}) \end{cases}$$

If $|\boldsymbol{F}_{t-1}^{(\mathrm{m})} - K_{\mathrm{scale}}\, \boldsymbol{F}_{t-1}^{(\mathrm{s})}| > |\boldsymbol{F}_{\mathrm{th}}|$, $\boldsymbol{F}_t^{(\mathrm{m})}$ is gradually increased by adding $\boldsymbol{F}_{t-1}^{(\mathrm{m})}$ to $K_i \boldsymbol{F}_{\mathrm{th}}$.

$\boldsymbol{F}_{\mathrm{th}}$: Force threshold (0.003 N/ms)

K_i : $1.000 + 0.001i$ ($i \geq 1$)

Stabilization control by viscosity

Position of robot

$$\boldsymbol{S}_t = \begin{cases} \boldsymbol{M}_{t-1} + \boldsymbol{V}_{t-1} - C_{\mathrm{d}}(\boldsymbol{M}_{t-1} - \boldsymbol{S}_{t-2}) & (\,|\boldsymbol{V}_{t-1}| \leq V_{\max}\,) \\ \boldsymbol{M}_{t-1} + V_{\max}\dfrac{\boldsymbol{V}_{t-1}}{|\boldsymbol{V}_{t-1}|} - C_{\mathrm{d}}(\boldsymbol{M}_{t-1} - \boldsymbol{S}_{t-2}) & (\text{otherwise}) \end{cases}$$

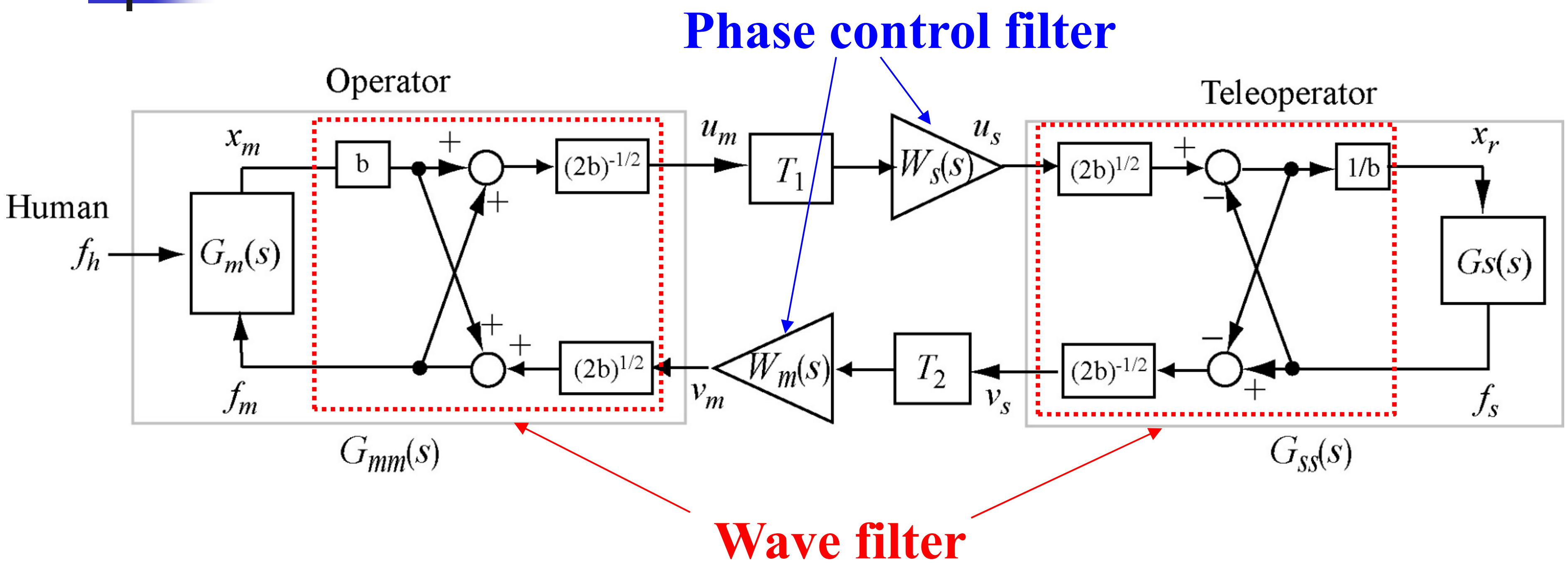
We produce the viscosity by restricting the movement distance of the industrial robot to some extent.

C_{d} : Coefficient related to viscosity (0.95)

Force outputted at master terminal

Same as no stabilization control

Stabilization control with filter



The control uses the wave filter in combination with the phase control filter.

Experiment method (1/2)

*4 E. Taguchi *et al.*, IEICE General Conference, B-11-17, Mar. 2018.

- **We handle work in which the user pushed and dropped only the top building blocks with a wooden stick[*4].**

- **To move the stick in almost the same way, building blocks were piled up front and back of the initial position of the stick before the experiment began.**

- **In order to move the stick at almost the same speed, the user dropped the first building block at about 5 second and the second building block at about 15 second.**

- **We disabled the movement of each industrial robot in the left and right direction.**

Demo video of system operation

(No network delay)

Experiment method (2/2)

- **The ratio of the moving distance of the haptic interface device to that of the industrial robot was 2:1, and the ratio of the force was 1:2.**

- **We generated a constant delay (called the *additional delay*) for each packet transmitted between the two terminals by a network emulator.**

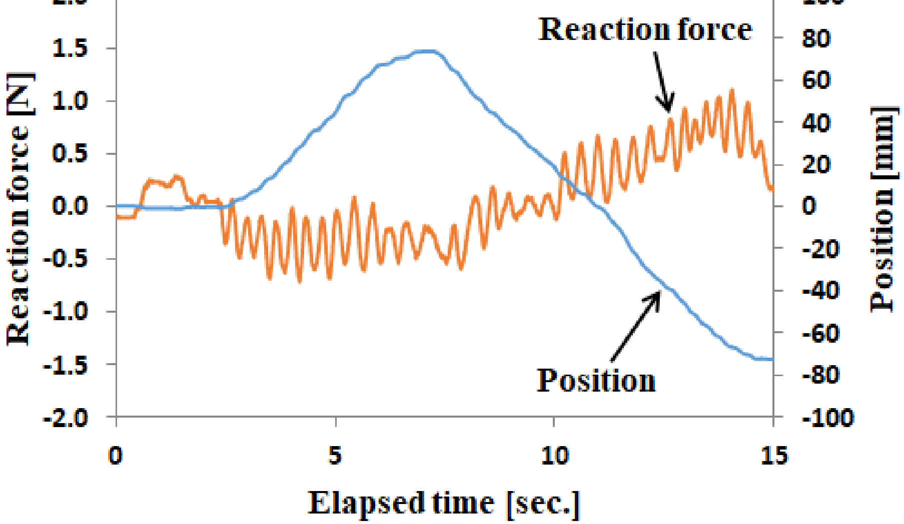
- **We dealt with the case where the stabilization control was not carried out as well as the cases where the three types of control were performed.**

- **We measured the reaction force and position outputted by the haptic interface device.**

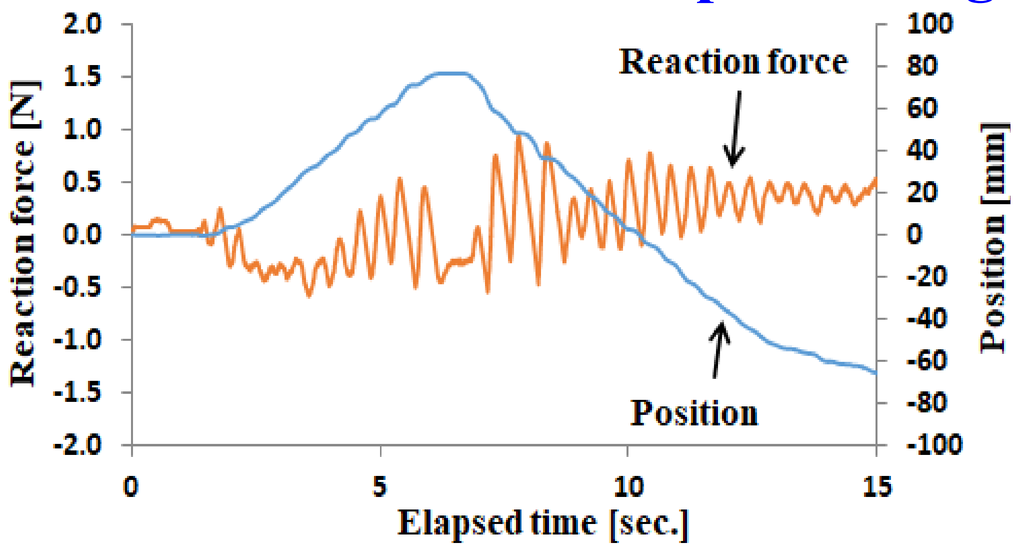
Experiment results (1/2)

(Additional delay: 0 ms)

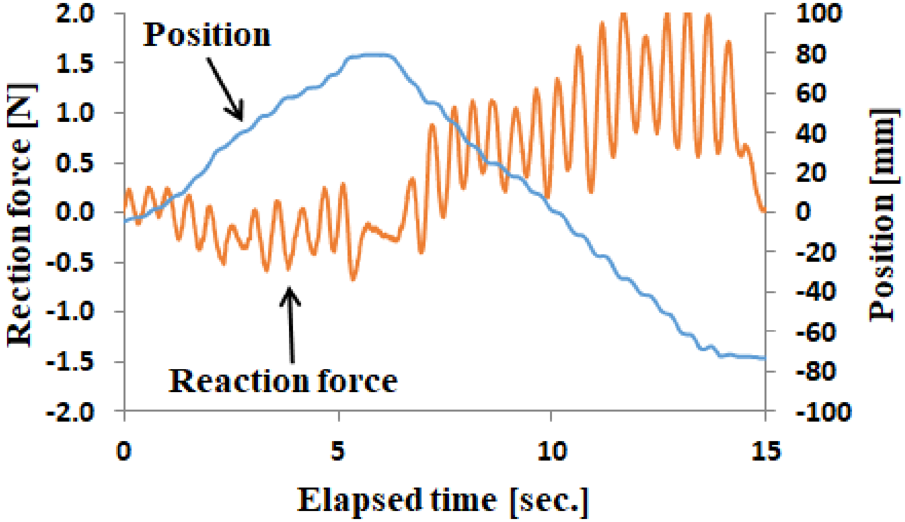
No stabilization control



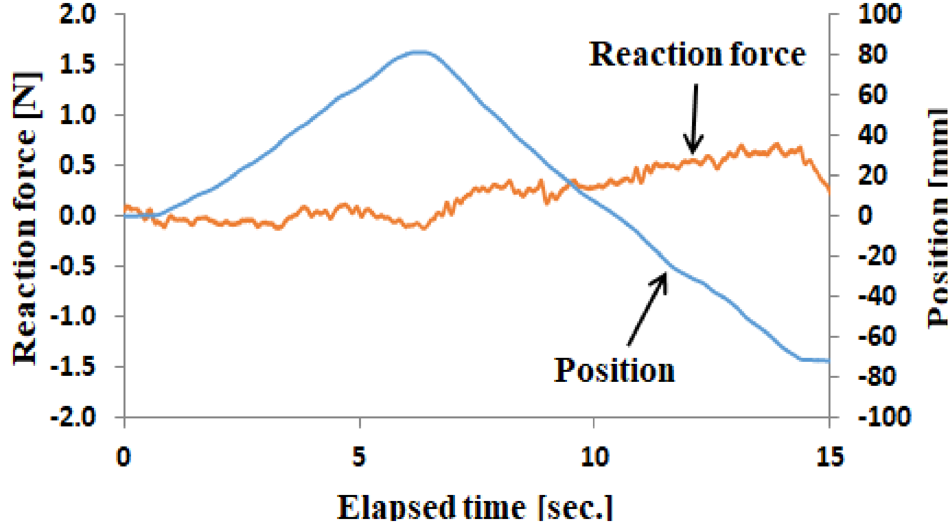
Reaction force control upon hitting



Stabilization control with viscosity



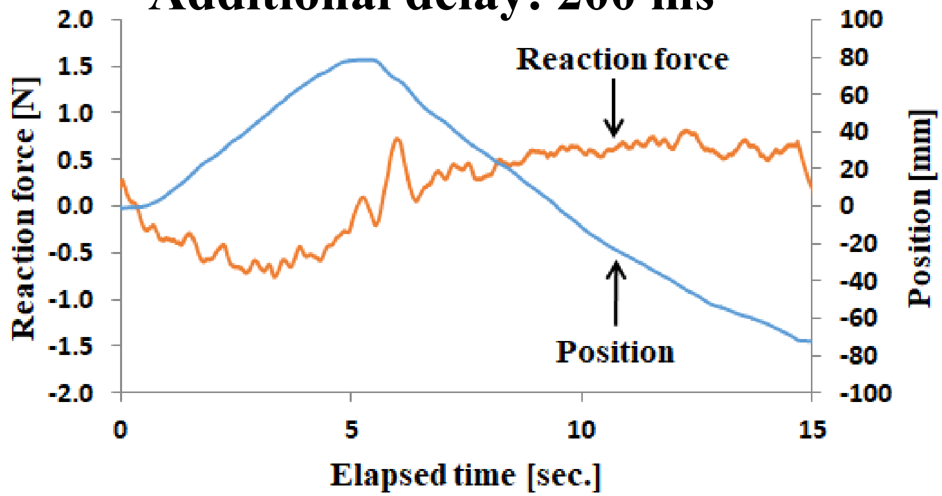
Stabilization control with filter



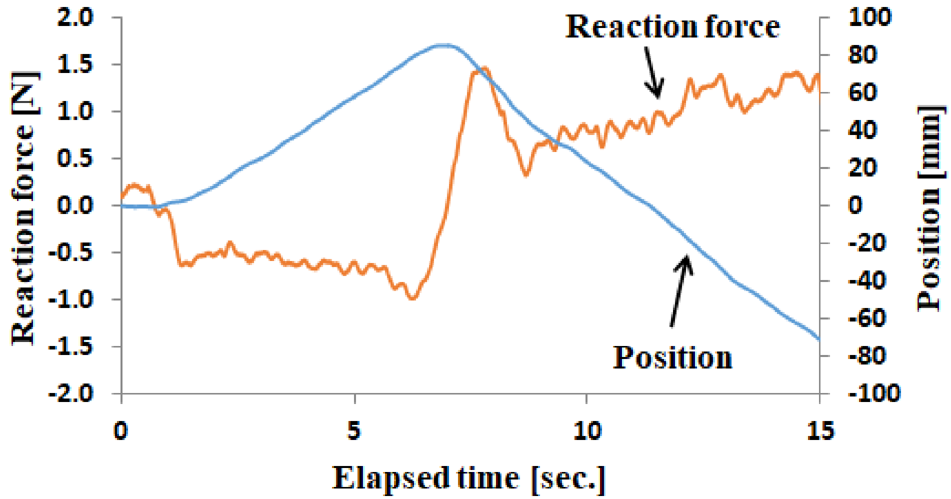
Experiment results (2/2)

Stabilization control with filter

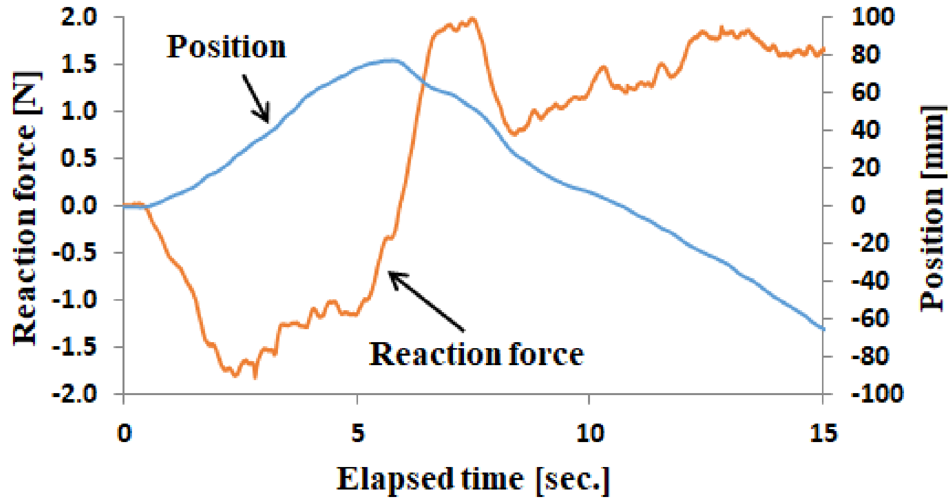
Additional delay: 200 ms



Additional delay: 400 ms



Additional delay: 800 ms



Conclusion

- **We apply the three types of stabilization control which are reaction force control upon hitting, stabilization control by viscosity and stabilization control with filters to the cooperative work of the two systems.**
- **We investigate which types of stabilization control is the most effective by experiment.**

- **The stabilization control with filter is the most effective.**

Future work

- Experiment when each of two users employs a haptic interface devices

- Experiments with various types of work