Influences of Network Delay and Movement Velocity under Adaptive Viscoelasticity Control with Prediction

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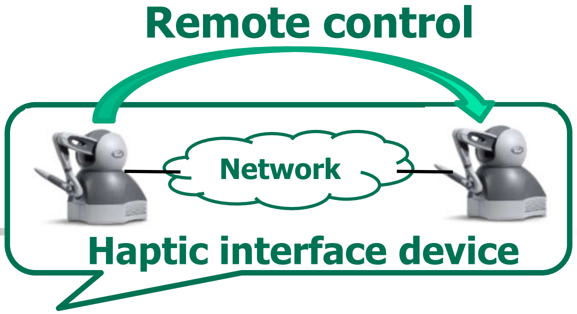
Background



Remote control system with haptics in which a user can remotely operate **a haptic interface device** by using **another haptic interface device** while watching video

→ Improvement of the efficiency and accuracy of work because the users can perceive the shape, surface smoothness, weight of each remote object

When we use a network that does not guarantee QoS (Quality of Service) like the Internet

↓ **Network delay, delay jitter, and packet loss**

Degradation of QoE (Quality of Experience) such as operability of haptic interface device

Previous Work

*1 T. Abe *et al.*, IEICE Trans. Commun. (Japanese Edition), vol. J103-B, no. 1, pp. 38-46, Jan. 2020
*2 L. Wen *et al.*, Tokai-Section Joint Conference, G5-2, Sep. 2020.

Adaptive viscoelasticity control is proposed for a remote control system with haptics[*1].

- The interactivity is damaged when the network delay is large.
- The difference between the trajectory of the device operated by a user and that of the remote device is large.

Prediction control can be carried out in conjunction with the adaptive viscoelasticity control[*2].

- There exists the optimum prediction time according to the network delay[*2].

- The optimum prediction time may be related to the movement velocity of the device as well as the network delay.
- The relationship between the movement velocity and optimum prediction time has not been clarified so far.

Purpose

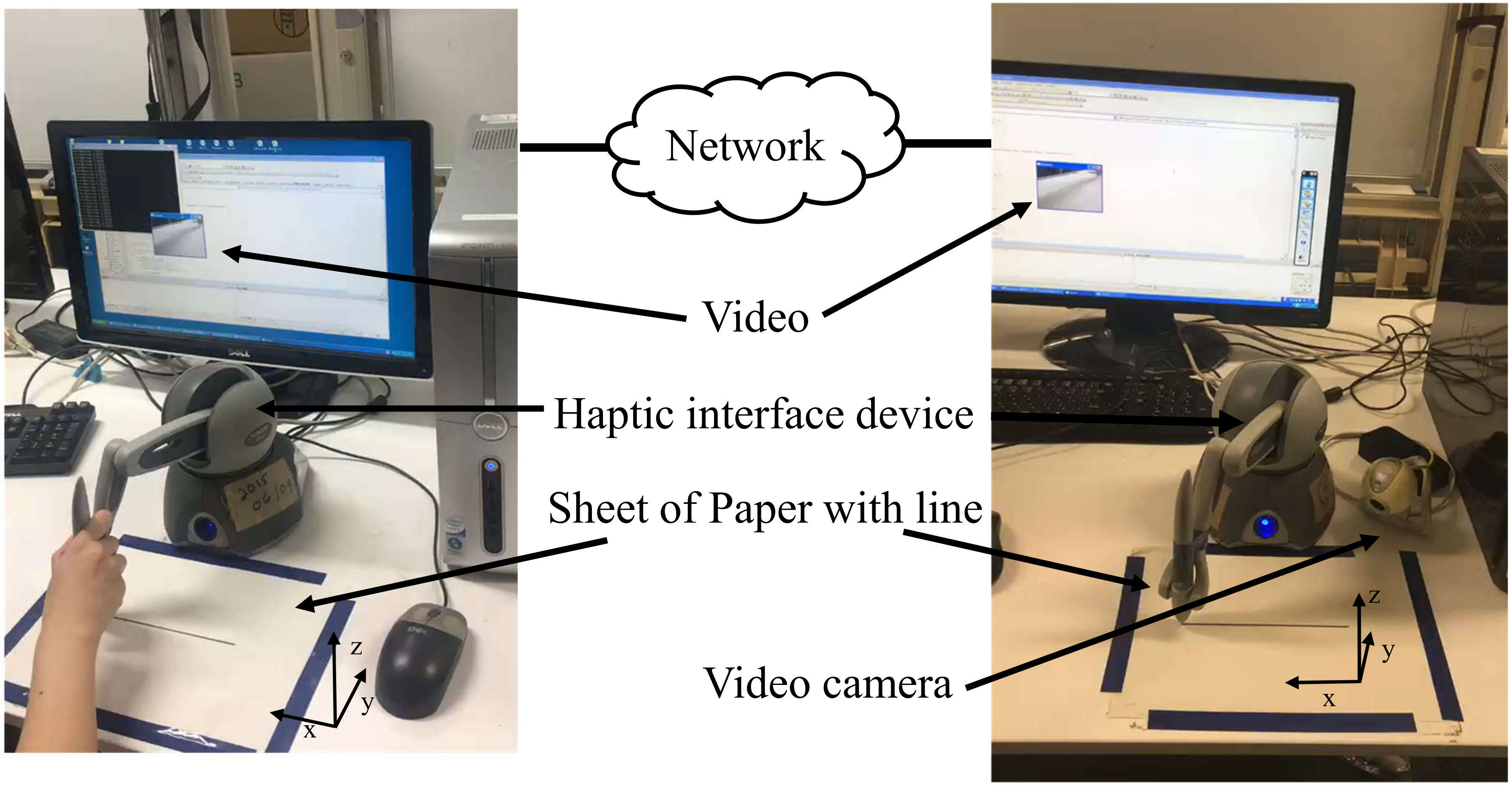
This work

- Investigate influences of the network delay and movement velocity under the adaptive viscoelasticity control with prediction.

Remote Control System with Haptics

Master terminal

Slave terminal



Network

Video

Haptic interface device

Sheet of Paper with line

Video camera

*1 T. Abe *et al*., IEEE ICCE-TW, pp. 133-134, May 2018.

Calculation Method of Reaction Force

Master terminal

$$\boldsymbol{F}_t^{(\mathrm{m})} = K_s\left(\boldsymbol{S}_{t-1}^{(\mathrm{m})} - \boldsymbol{M}_{t-1}^{(\mathrm{m})}\right) + K_d(\dot{\boldsymbol{S}}_{t-1}^{(\mathrm{m})} - \dot{\boldsymbol{M}}_{t-1}^{(\mathrm{m})})$$ *1

$\boldsymbol{F}_t^{(\mathrm{m})}$: Reaction force of master terminal at time t ($t > 0$)

$\boldsymbol{S}_{t-1}^{(\mathrm{m})}, \boldsymbol{M}_{t-1}^{(\mathrm{m})}$: Position vector of haptic interface device of slave/master terminal at time t ($t > 0$)

$\dot{\boldsymbol{S}}_{t-1}^{(\mathrm{m})}, \dot{\boldsymbol{M}}_{t-1}^{(\mathrm{m})}$: Velocity of slave/master terminal at time t ($t > 0$)

K_s : Elasticity coefficient

K_d : Viscosity coefficient

Slave terminal

$$\boldsymbol{F}_t^{(\mathrm{s})} = K_s\left(\boldsymbol{M}_{t-1}^{(\mathrm{s})} - \boldsymbol{S}_{t-1}^{(\mathrm{s})}\right) + K_d(\dot{\boldsymbol{M}}_{t-1}^{(\mathrm{s})} - \dot{\boldsymbol{S}}_{t-1}^{(\mathrm{s})})$$

Adaptive Viscoelasticity Control

The **adaptive elasticity control** and **adaptive viscosity control** are carried out together at each terminal.

$$\boldsymbol{F}_t^{(\mathrm{m})} = \overbrace{K_s\left(\boldsymbol{S}_{t-1}^{(\mathrm{m})} - \boldsymbol{M}_{t-1}^{(\mathrm{m})}\right)}^{\textbf{Elasticity}} + \overbrace{K_d(\dot{\boldsymbol{S}}_{t-1}^{(\mathrm{m})} - \dot{\boldsymbol{M}}_{t-1}^{(\mathrm{m})})}^{\textbf{Viscosity}}$$

Elasticity is the property that the deformation occurs when force is applied to an object, and the deformation returns to its original state when the force disappears.

Viscosity is force or resistance exerted by fluids when we move something through the fluids (e.g., water and oil).

Adaptive Elasticity Control

The elasticity coefficient K_s is dynamically changed according to the network delay.

$$\boxed{K_s = 9/(2D + 90)}\ ^{*1}$$

D : One-way network delay between the two terminals

*1 T. Abe *et al.*, IEEE ICCE-TW, pp. 133-134, May 2018.

Adaptive Viscosity Control

The viscosity coefficient K_d is dynamically changed according to the network delay and the moving velocity of a haptic interface device.

$$K_\mathrm{d} = \begin{cases} 1.02 \times 10^{-5} D + 4.2 \times 10^{-5} v - 2.03 \times 10^{-4} & (D \le D_\mathrm{peak}) \\ -6.31 \times 10^{-6} D - 2.12 \times 10^{-4} v + 2.99 \times 10^{-3} & (D > D_\mathrm{peak}) \end{cases}$$

$$D_\mathrm{peak} = -20v + 228$$ *1

D_peak : Network delay when the optimum viscosity coefficient has peak value

v : Moving velocity

*1 T. Abe *et al*., IEEE ICCE-TW, pp. 133-134, May 2018.

Prediction Control

Each terminal outputs position information by predicting the future position after the prediction time from the received position information.

$$\boldsymbol{P}_{t+\Delta t}^{(\mathrm{predict})} = \boldsymbol{P}_t + (\boldsymbol{P}_t - \boldsymbol{P}_{t-1})\Delta t$$

*3

$\boldsymbol{P}_t$: Position vector received from other terminal at time t (ms)

Δt : Prediction time

*3 P. Huang *et al.*, IJCNS, vol. 5, no. 6, pp. 321-331, June 2012.

*2 L. Wen *et al*., Tokai-Section Joint Conference, G5-2, Sep. 2020.

Assessment Method

- Conducted work in which a user moves the haptic interface device at several velocities to right and left (the *x*-axis) along a line with length of 16 cm for 30 seconds.

- The following velocities were selected:
  2.67 cm/sec. (= 8 cm/ 3 sec.)
  5.33 cm/sec. (= 16 cm/ 3 sec.) *2
  10.67 cm/sec. (= 32 cm/ 3 sec.)

- Prediction time : 0 ms — 20 ms

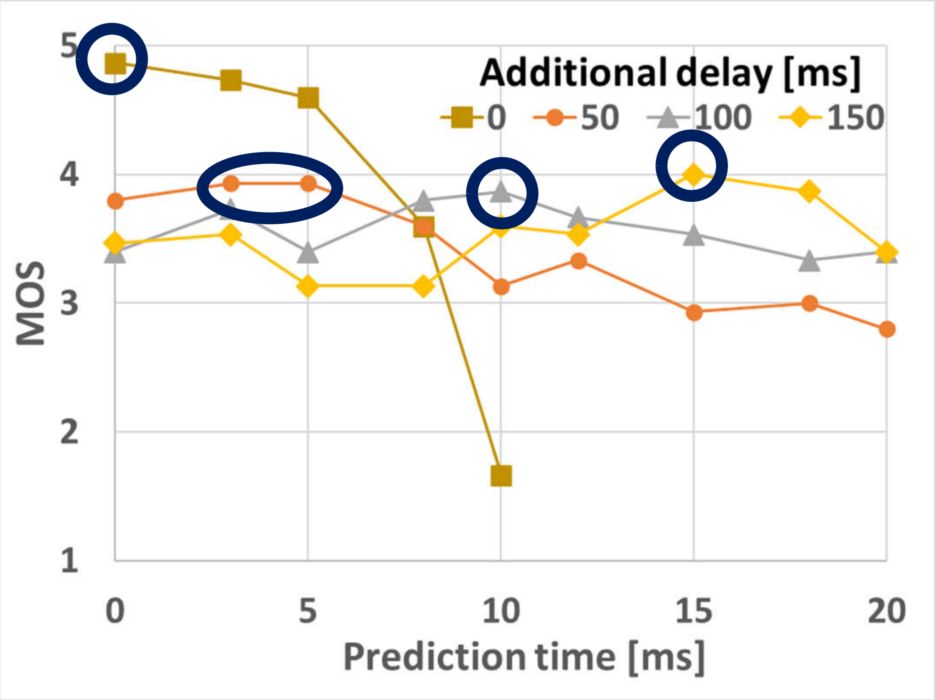
- Gave a score according to the five-grade impairment scale.

- Obtained the mean opinion score (MOS) by averaging all the scores of 15 subjects.

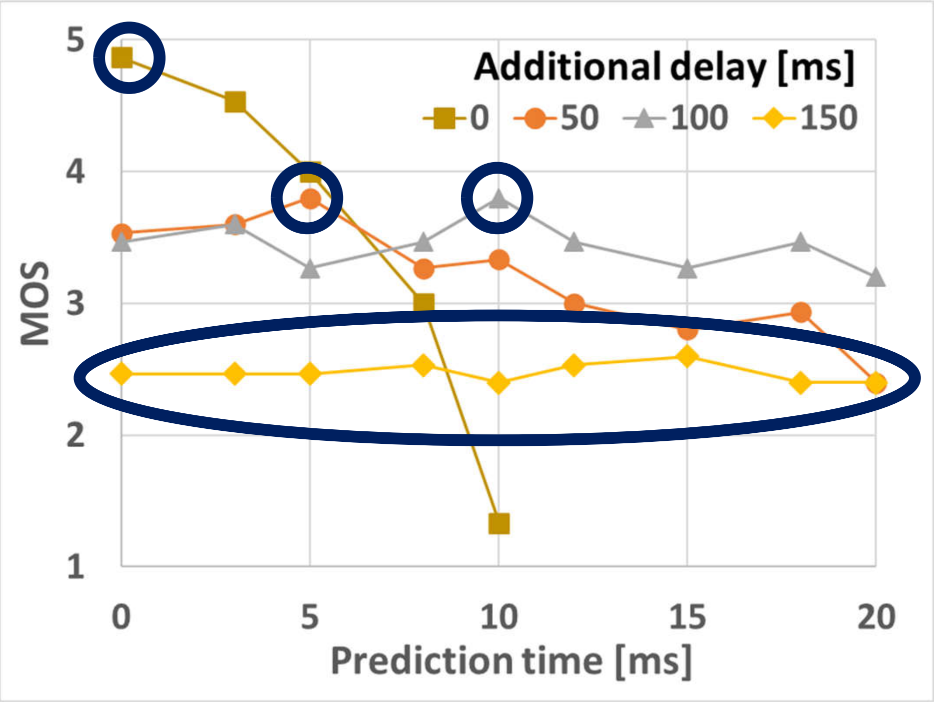
Five-grade impairment scale

Score	Description
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Assessment Results (1/2)

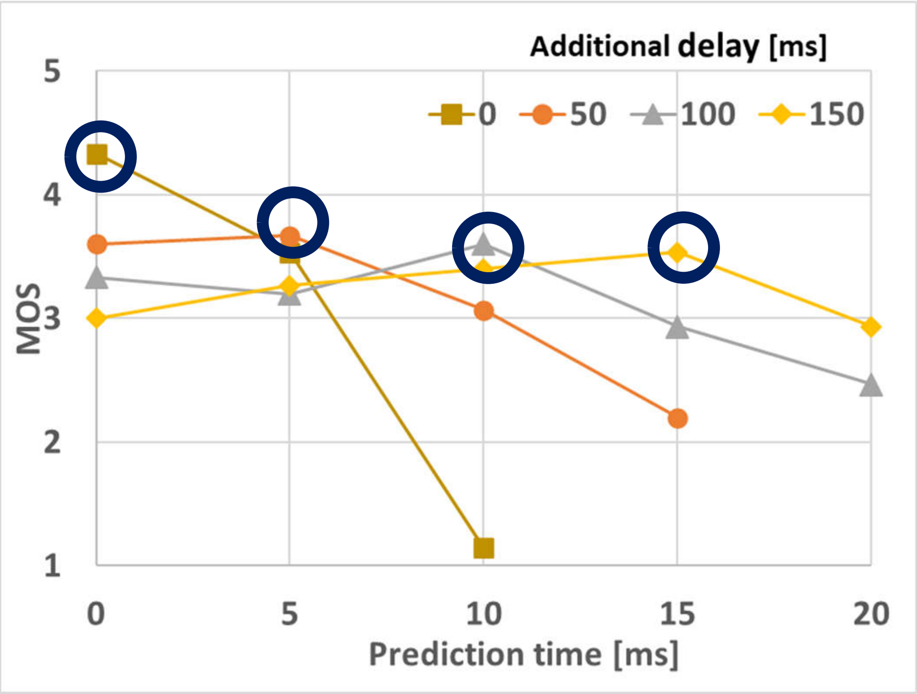


(a) Velocity: 2.67 cm/sec.



(b) Velocity: 10.67 cm/sec.

Assessment Results (2/2)



(c) Velocity: 5.33 cm/sec.[*2]

Optimum prediction times for additional delays and velocities.

Additional delay [ms]	Velocity [cm/sec.]	Optimum prediction time [ms]
0	2.67	0
	5.33	
	10.67	
50	2.67	3 - 5
	5.33	5
	10.67	
100	2.67	10
	5.33	
	10.67	
150	2.67	15
	5.33	
	10.67	-

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*2 L. Wen *et al.*, Tokai-Section Joint Conference, G5-2, Sep. 2020.

Conclusions

We investigated the influences of the network delay and the movement velocity under the adaptive viscoelasticity control with prediction.

- ✓ There exists the optimum prediction time depending on the network delay.
- ✓ The optimum prediction time is hardly dependent on the movement velocity of the haptic interface device.
- ✓ As the network delay becomes larger, the optimum prediction time increases.
- ✓ The effectiveness of the control is not good when the network delay is approximately 150 ms and the movement velocity is high.

Future Work

*4 L. Chen *et al.*, IEEE ICCE-TW, Sep. 2020.

We plan to examine influences of the network delay and movement velocity under the stabilization control by viscosity with prediction.

- ➢ The stabilization control by viscosity is superior to the adaptive viscoelasticity control when the network delay is large.[*4]
- ➢ The influence of the movement velocity on the stabilization control by viscosity has not sufficiently been clarified so far.