QoE Assessment of Adaptive Viscoelasticity Control with Prediction in Remote Control System

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Background

Each user can touch and move a remote object by using a haptic interface device.

- Remote control
  remotely operate haptic interface devices while watching video.
- We can largely improve the efficiency and accuracy of remote work.

When we use them through a network like the Internet

Network delay, delay jitter and packet loss

QoE (Quality of Experience) degradation

Problems

*1 T. Abe et al., IEICE Trans. Commun. (Japanese Edition), vol. J103-B, no. 1, pp. 38-46, Jan. 2020
*2 P. Huang et al., IJCNS , vol. 5, no. 6, pp. 321-331, June 2012.

Previous work

The adaptive viscoelasticity control is proposed for a remote control systems with haptics*1.

The effectiveness of the control is demonstrated by QoE assessment.

- 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.

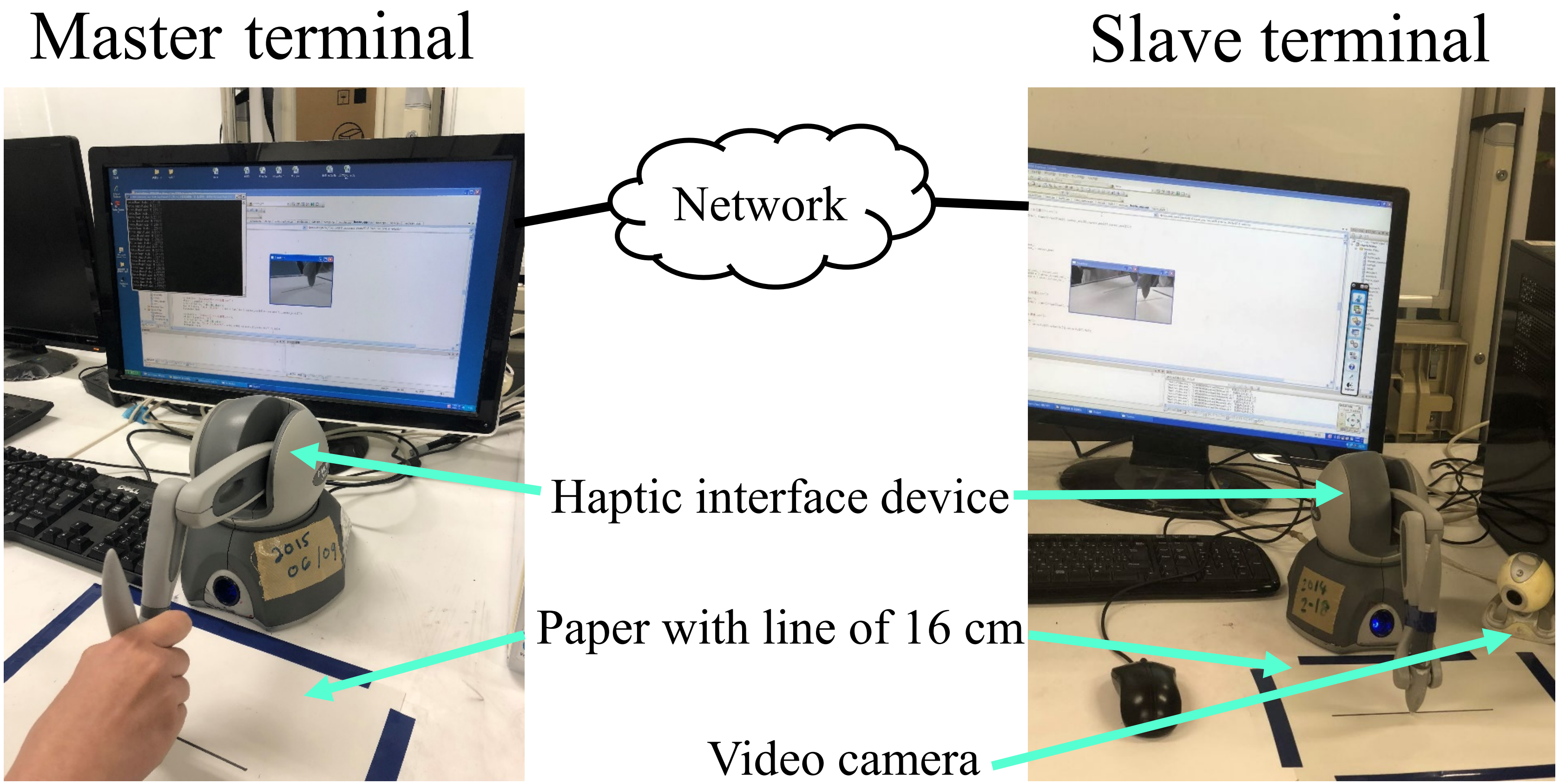
We carry out the prediction control*2 in conjunction with the adaptive viscoelasticity control.
The effect of the control has not been clarified quantitatively so far.

Purpose

This work

- We propose the adaptive viscoelasticity control with prediction in the remote control system.
- We illustrate that there exists the optimum prediction time according to the network delay by QoE assessment.

Remote Control System



Calculation for Reaction Force

Master terminal

$$\boldsymbol{F}_t^{(\mathrm{m})} = K_\mathrm{s}\left(\boldsymbol{S}_{t-1}^{(\mathrm{m})} - \boldsymbol{M}_{t-1}^{(\mathrm{m})}\right) + K_\mathrm{d}\left(\dot{\boldsymbol{S}}_{t-1}^{(\mathrm{m})} - \dot{\boldsymbol{M}}_{t-1}^{(\mathrm{m})}\right) \quad (1)$$

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

K_s : Elasticity (spring) coefficient

K_d : Viscosity (damper) coefficient

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

$\dot{\boldsymbol{M}}_t^{(\mathrm{m})}, \dot{\boldsymbol{S}}_t^{(\mathrm{m})}$: Velocity vector of the haptic interface device of the master and slave terminal at time t ($t > 0$)

Slave terminal

$$\boldsymbol{F}_t^{(\mathrm{s})} = K_\mathrm{s}\left(\boldsymbol{M}_{t-1}^{(\mathrm{s})} - \boldsymbol{S}_{t-1}^{(\mathrm{s})}\right) + K_\mathrm{d}\left(\dot{\boldsymbol{M}}_{t-1}^{(\mathrm{s})} - \dot{\boldsymbol{S}}_{t-1}^{(\mathrm{s})}\right) \quad (2)$$

Adaptive Viscoelasticity Control

Adaptive elasticity control

Optimum elasticity coefficient $\widehat{K}_s$ is determined by the network delay D (ms) as follows:

$$\widehat{K}_s = 9/(2D + 90) \quad (3)$$

Adaptive viscosity control

Optimum viscosity coefficient $\widehat{K}_d$ is calculated as follows:

$$\widehat{K}_d = \begin{cases} 1.02 \times 10^{-5}D + 4.2 \times 10^{-5}v - 2.03 \times 10^{-4} \ (D \leq D_{peak}) \\ -6.31 \times 10^{-6}D - 2.12 \times 10^{-4}v + 2.99 \times 10^{-3} \ (D > D_{peak}) \end{cases} \quad (4)$$

$$D_{peak} = -20v + 228 \quad (5)$$

D_{peak}: Network delay when the optimum viscosity coefficient has the peak value

v : Moving speed of the haptic interface device.

Prediction Control

Prediction Control

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

$$\boldsymbol{P}_{t+\Delta t} = \boldsymbol{P}_t + (\boldsymbol{P}_t - \boldsymbol{P}_{t-1})\Delta t \quad (6)$$

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

Δt : Prediction time

Experiment Method (1/2)

- Conducted work in which a user moves the haptic interface device from side to side (in the x axis direction) along a line with length of 16 cm drawn on a paper for 30 seconds (repeated about 5 times).

- Presented pairs of the network delay and prediction time in random order for each subject.

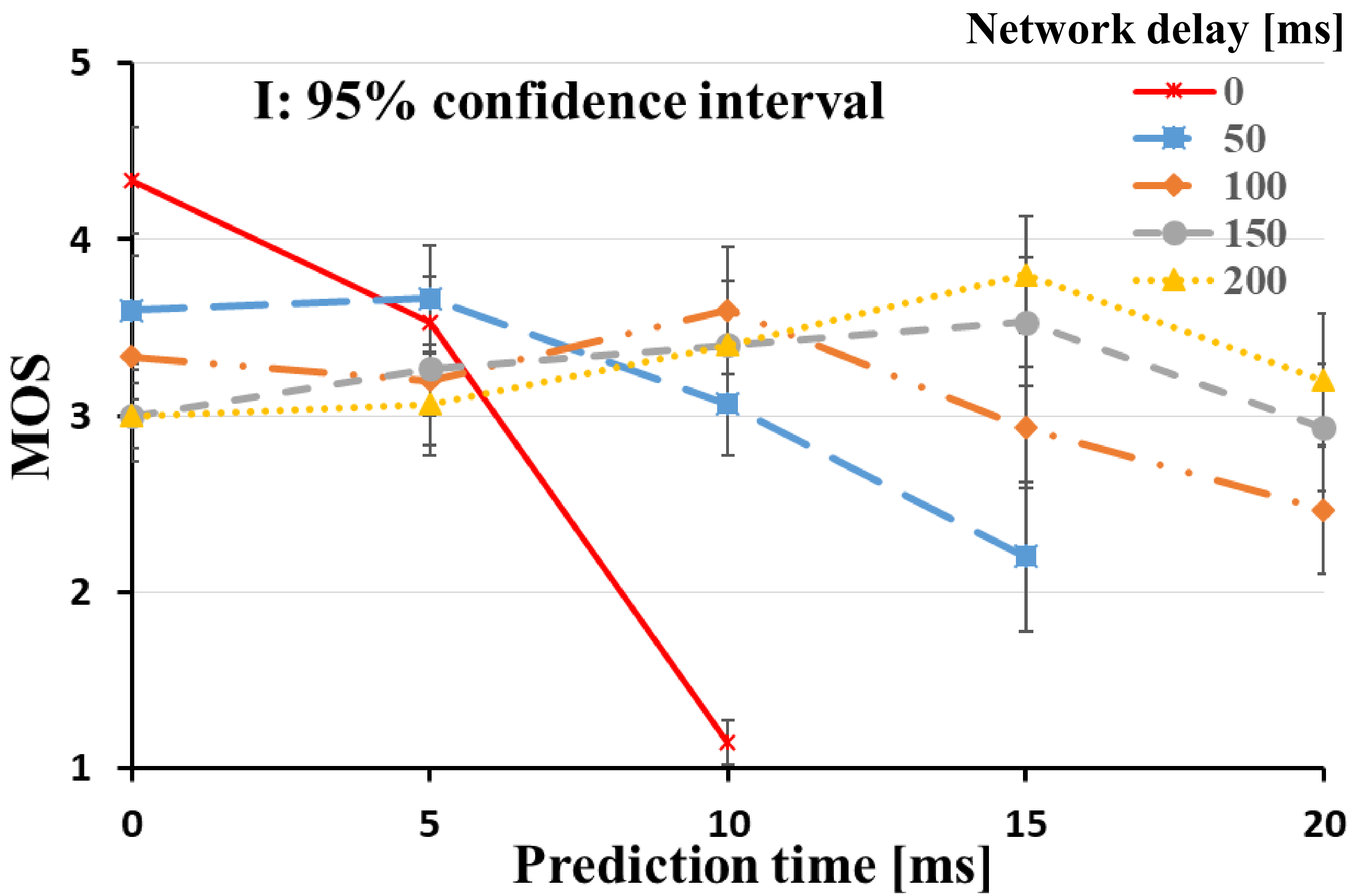
Experiment Method (2/2)

- Gave a score according to the five-grade impairment for each pair.
- Obtained the mean opinion score (MOS) by averaging all the scores of 15 subjects (11 males and 4 females) whose ages were between 21 and 29.

Five-grade impairment scale

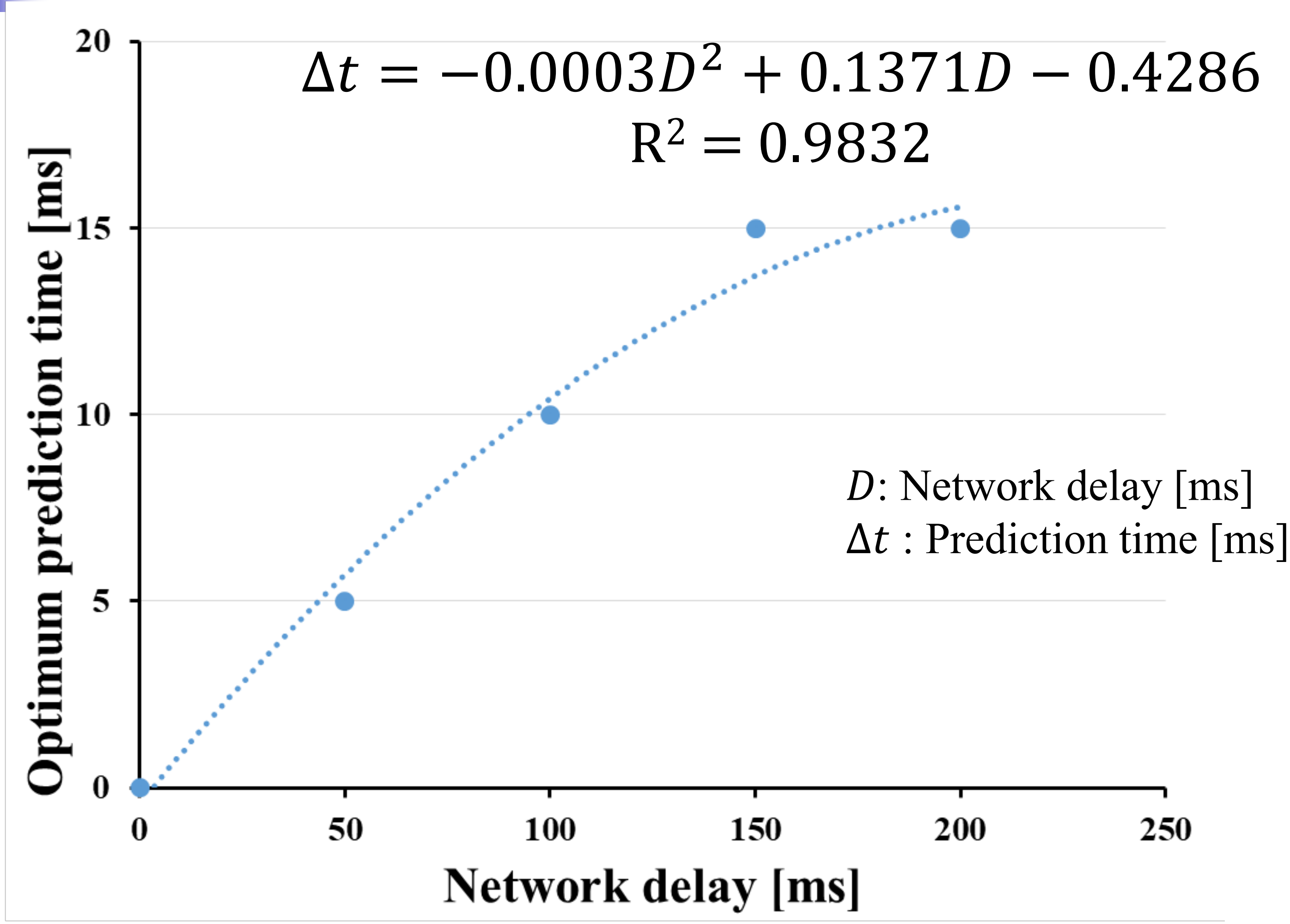
Score	Description
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Assessment Results (1/2)



MOS versus prediction time

Assessment Results (2/2)



Optimum prediction time versus network delay

Conclusions and Future Work

Conclusions

- We used prediction control to improve the interactivity of the remote control system with haptics under the adaptive viscoelasticity control.
- We investigated the effect of the prediction control on the operability by QoE assessment.

✓ There exists the optimum prediction time depending on the network delay.
✓ As the network delay becomes larger, the optimum prediction time increases.

Future Work

We plan to use the obtained results for further improvement of the operability of the haptic interface device.