QoE Assessment of Adaptive Viscoelasticity Control in Remote Control System with Haptic and Visual Senses

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Outline

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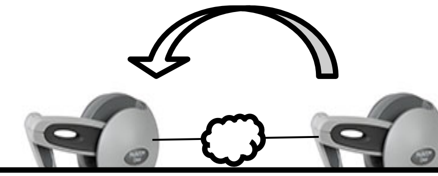
- Purpose
- Remote Control System with Haptic and Visual Senses
- Calculation Method of Reaction Force
- Adaptive Viscoelasticity Control
- Investigation Method and Results
- QoE Assessment Method and Results
- Conclusion and Future Work

Background

Remote control



Research on remote control systems
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Elasticity is perceived w
stretching a spring or ru

Viscosity is perceived when moving object in water or oil.

By using a haptic interfac vice, because a feels the reaction force (consisting of elasticity and viscosity), the work efficiency can be improved largely.

Transmission of information about visual and haptic senses via network without QoS (Quality of Service) guarantee

Network delay, delay jitter, and packet loss →

Degradation of QoE (Quality of Experience)

QoS control

Previous Work

*1 M. Fujimoto *et al*., IEICE Trans. Commun. (Japanese Edition), J87-B, no. 4, pp. 589-592, Apr. 2004.
*2 K. Matsunaga *et al*., IEICE Technical Report, CQ2013-90, Mar. 2014.
*3 Y. Komatsu *et al*., IEICE Society Conference, B-11-16, Sep. 2017.

Previous work

We applied the adaptive elasticity control,*1 which dynamically selects the optimum elasticity coefficient according to the network delay, to a remote control system with haptic and visual senses.*2

⇨ The effectiveness of the control was demonstrated by QoE (Quality of Experience) assessment.

We proposed the adaptive viscosity control, which dynamically selects the optimum viscosity coefficient according to the network delay and the moving velocity of a haptic interface device.*3

⇨ The effectiveness of the control was demonstrated by QoE assessment. We illustrated that the optimum viscosity coefficient has a certain range.

Problem

If the two types of control are used in combination, higher quality of control may be realized.

⇨ However, such a study has not been done so far.

Purpose

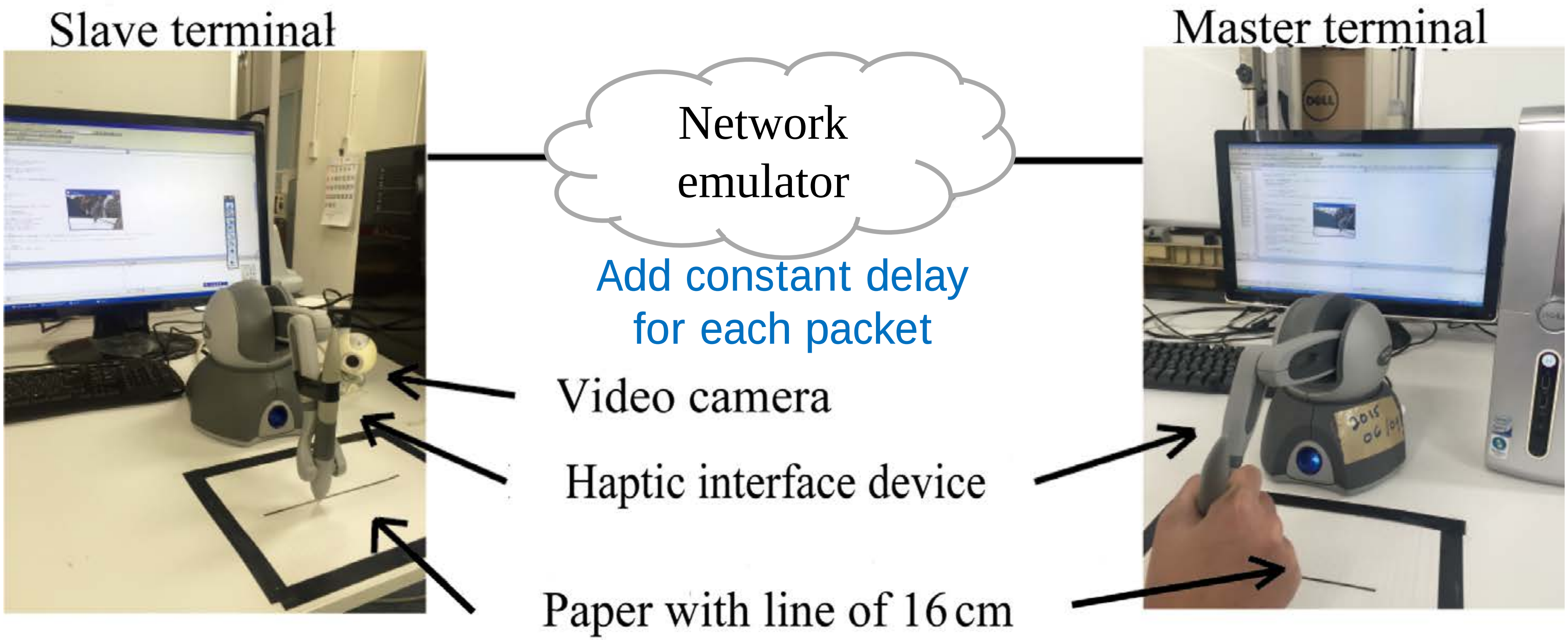
This work

Propose adaptive viscoelasticity control

- We propose the adaptive viscoelasticity control by combining the adaptive elasticity control and the adaptive viscosity control.
- We investigate the effectiveness of the proposed control by QoE assessment.

Remote Control System with Haptic and Visual Senses

*2 Y. Komatsu *et al*., IEICE Society Conference, B-11-16, Sep. 2017.



Configuration of Experiment System*2

Demonstration of Experiment

Slave terminal

Master terminal

Calculate of Reaction Force

Master terminal

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

K_s : Elasticity (spring) coefficient

K_d : Viscosity (damper) coefficient

$\boldsymbol{M}_{t-1}^{(\mathrm{m})}, \boldsymbol{S}_{t-1}^{(\mathrm{m})}$: Position vectors of master and slave terminals

$\dot{\boldsymbol{M}}_{t-1}^{(\mathrm{m})}, \dot{\boldsymbol{S}}_{t-1}^{(\mathrm{m})}$: Velocity of master and slave terminals

Slave terminal

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

Proposal of Adaptive Viscoelasticity Control

*1 K. Matsunaga *et al*., IEICE Technical Report, CQ2013-90, Mar. 2014.
*2 Y. Komatsu *et al*., IEICE Society Conference, B-11-16, Sep. 2017

➢ Optimum elasticity coefficient $\hat{K}_s$

A preliminary experiment showed that the optimum elasticity coefficient can be estimated only from the network delay (D).

Calculate from the adaptive elasticity control $\hat{K}_s = 9/(90+2D)$ [*1]

➢ Optimum viscosity coefficient $\hat{K}_d$

The optimum visc

Comprehensive quality considering strength of reaction force and vibration of device

Obtain the value (*called optimum* 1) immediately before each subject has not felt improvement of the operability of haptic interface device and, the value (*optimum value 2*) immediately before the subject has felt deterioration in operability of haptic interface device.

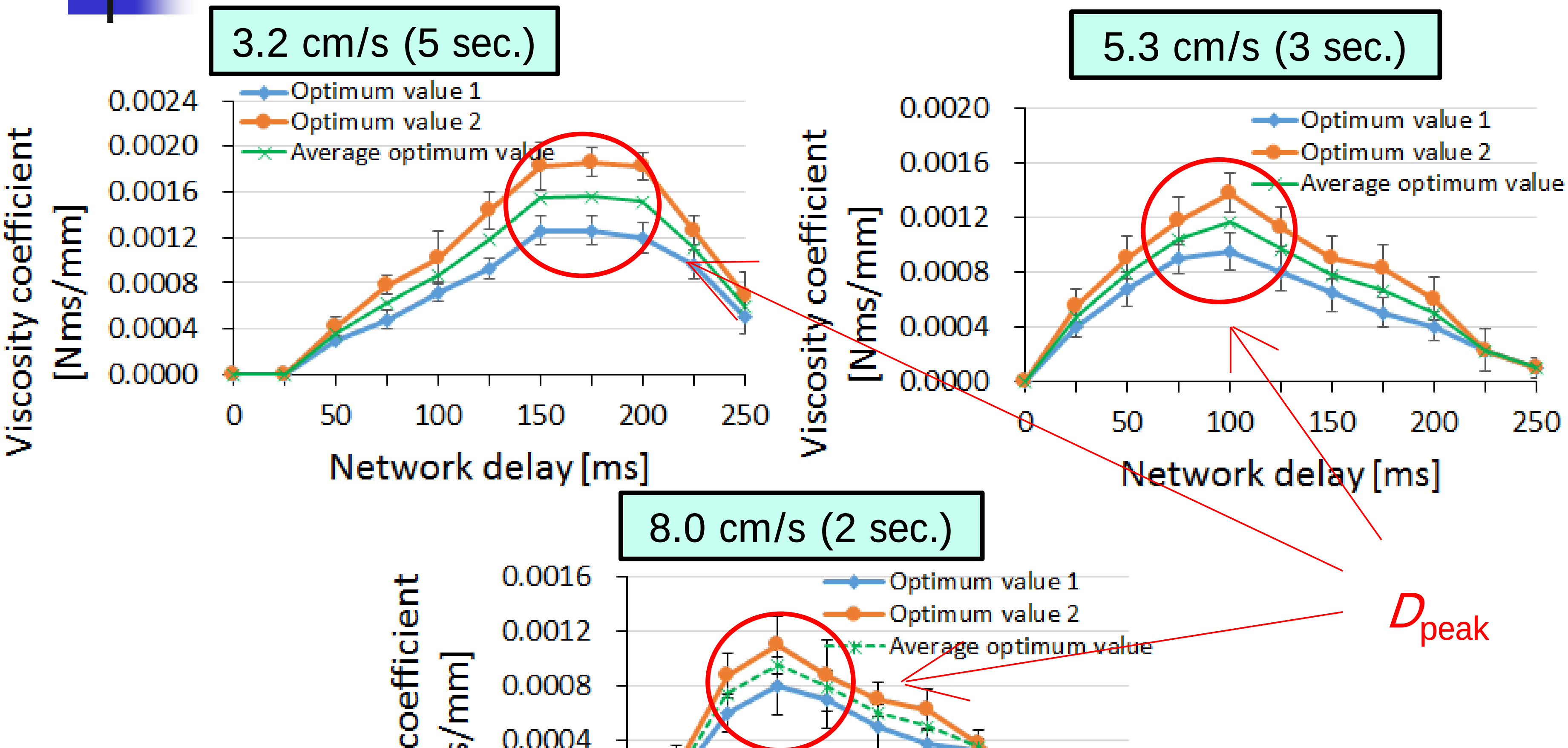
Investigation Method of Optimum Viscosity Coefficient

*1 K. Matsunaga et al., IEICE Technical Report, CQ2013-90, Mar. 2014.
*2 Y. Komatsu et al., IEICE Society Conference, B-11-16, Sep. 2017

Each subject moves the haptic interface device to the left and right.*2

- Time to move device along with line of 16 cm (velocity):
  - 3.2 cm/s (5 sec.), 5.3 cm/s (3 sec.), 8.0 cm/s (2 sec.)
- Move for 30 sec.
- Optimum elasticity coefficient $\widehat{K}s$:
  - Calculate from the adaptive elasticity control $\widehat{K}s = 9/(90+2D)$ *1
- Optimum viscosity coefficient $\widehat{K}\mathrm{d}$:
  - Increase the viscosity coefficient gradually from 0.0000 Nms/mm
  - Obtain the optimum values 1 and 2
  - Regard the average of the optimum values 1 and 2 as the optimum viscosity coefficient

Investigation Results



Because the shapes are asymmetry, the regression analysis is performed separately before and after D_{peak}

Regression Analysis

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

The contribution rate was 0.88.
D_{peak} can be estimated with high accuracy.

D_{peak} : Peak value of optimum viscosity coefficient
v : Moving velocity

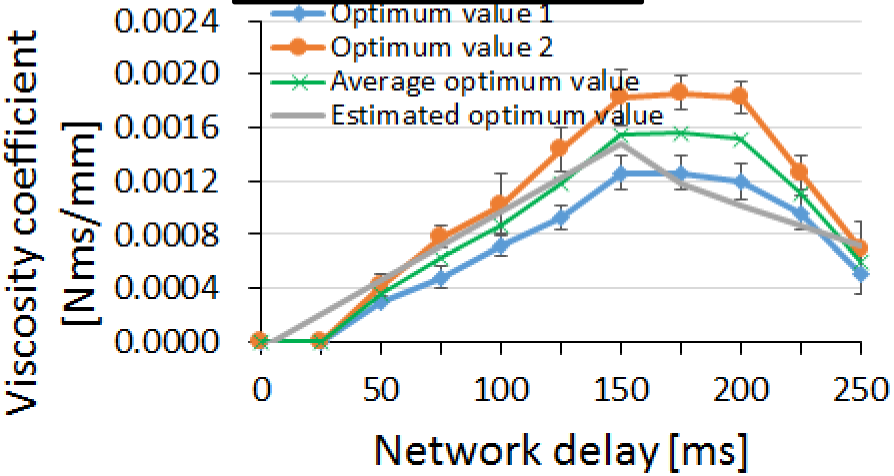
$$\hat{K}_{\mathrm{d}} = \begin{cases} 1.02\times10^{-5}D + 4.26\times10^{-5}v - 2.03\times10^{-4} & (D \leqq D_{\mathrm{peak}}) \\ -6.13\times10^{-6}D - 2.12\times10^{-4}v + 2.99\times10^{-3} & (D > D_{\mathrm{peak}}) \end{cases}$$

$\hat{K}_{\mathrm{d}}$: Optimum viscosity coefficient
D : Network delay
v : Moving velocity

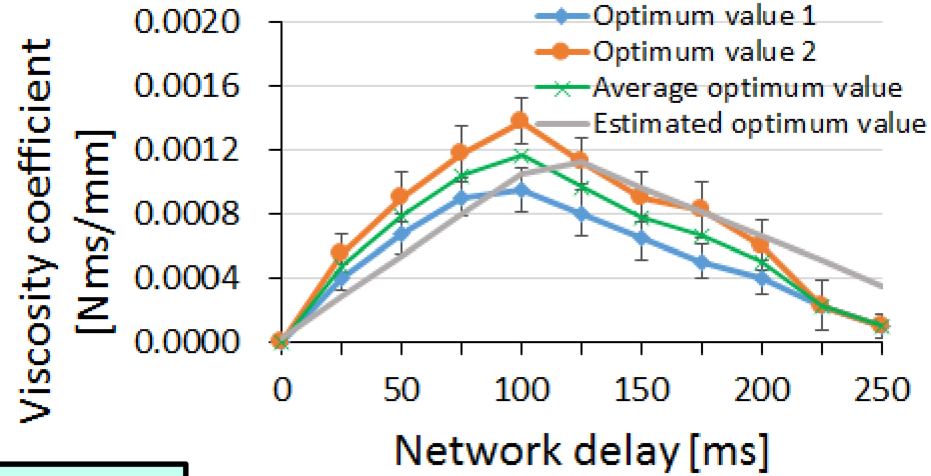
The contribution rates were 0.91 and 0.881.
$\hat{K}_{\mathrm{d}}$ can be estimated with high accuracy.

Results of Regression Analysis

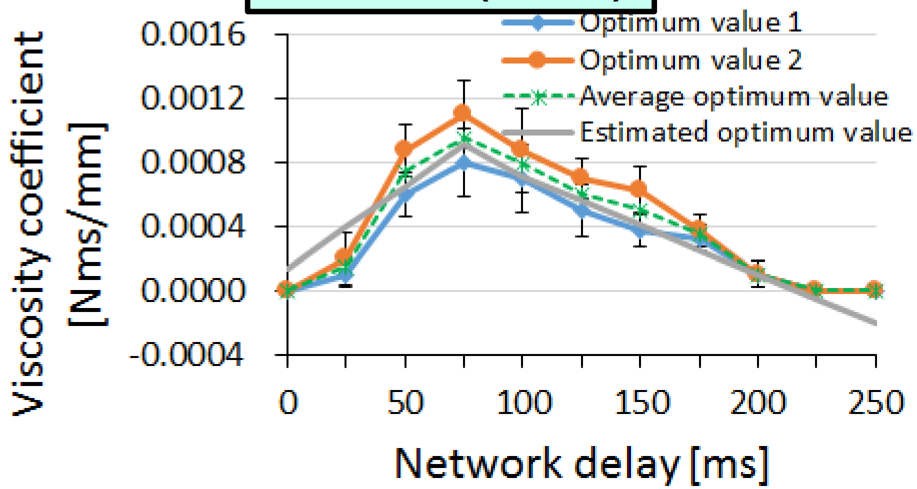
3.2 cm/s (5 sec.)



5.3 cm/s (3 sec.)



8.0 cm/s (2 sec.)



QoE Assessment Method

To examine effectiveness of adaptive viscoelasticity control

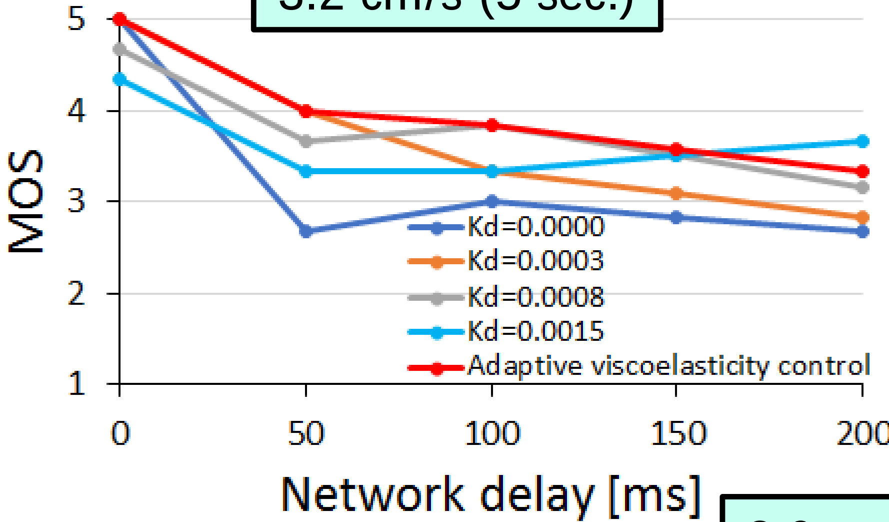
- Assessment method is same as investigation method.
- Each subject gave score on operability of haptic interface device with reference to operability in case of practice (network delay: 0 ms).
- Calculate MOS (Mean Opinion Score) by averaging all scores
- 15 subjects (ages were between 22 and 24)

5 Grade Impairment Scale

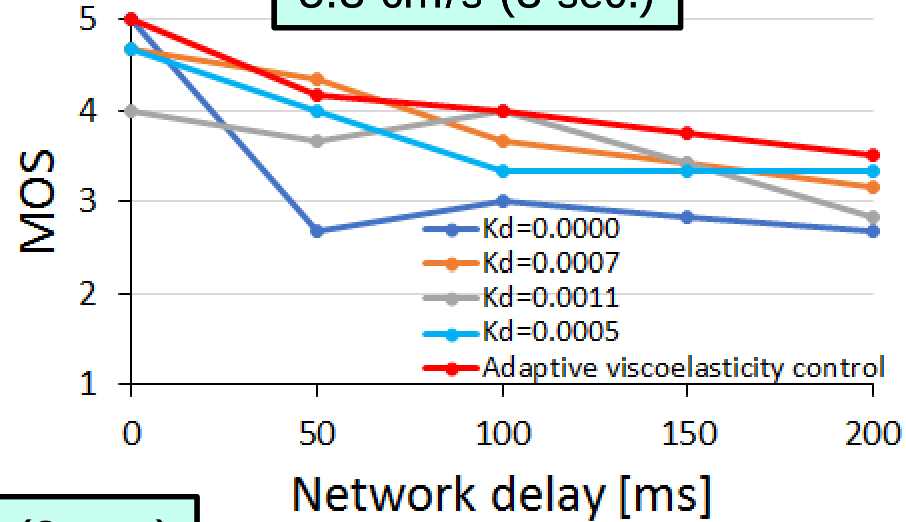
Score	Description
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

QoE Assessment Results

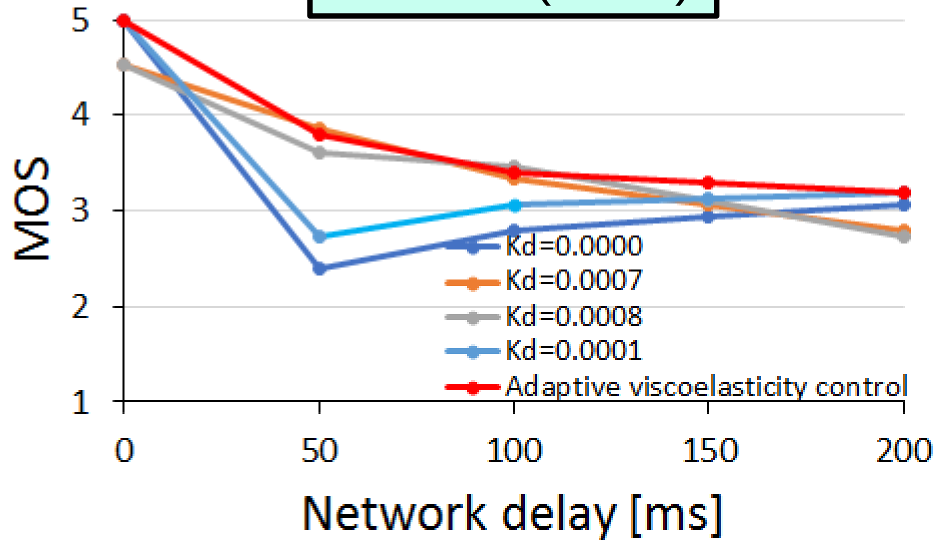
3.2 cm/s (5 sec.)



5.3 cm/s (3 sec.)



8.0 cm/s (2 sec.)



Conclusions

We proposed adaptive viscoelasticity control

・We investigated how large range the optimum viscosity coefficient has.

・We obtained equations that derives the optimum viscosity coefficient from the network delay and moving velocity by multiple regression analysis.

・We investigated the effectiveness of the proposed control by QoE assessment.

- As the network delay increases, the optimum viscosity coefficient becomes larger, and then it starts to decrease.
- The effectiveness of the adaptive viscoelasticity control was demonstrated by QoE assessment.

Future Work

- Examine dynamic behaviors of the adaptive viscoelasticity control when the network delay and moving velocity are changed
- Investigate the effectiveness of adaptive viscoelasticity control with more complicated work (e.g., writing characters and drawing figures)