Switching Scheme between Adaptive Viscosity Control and Stabilization Control by Viscosity in Remote Control System with Haptics

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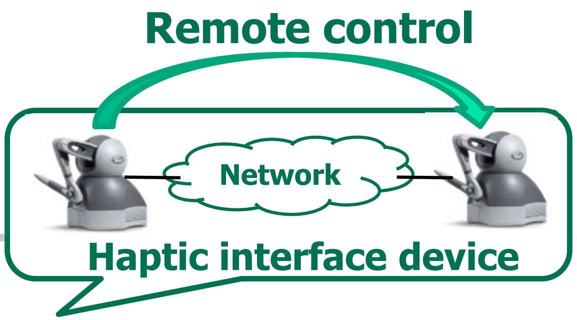
Background



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 reaction force

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

Strong force and unstable phenomena

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

Previous Work

Proposed the following three types of control for remote control system with haptics:

- ✓ **Adaptive elasticity control**[*1] → Suppress strong force
- ✓ **Adaptive viscosity control**[*1]
- ✓ **Stabilization control by viscosity**[*2]

} Suppress unstable phenomena

Adaptive viscosity control is better than **stabilization control by viscosity** when the network delay is small, and the latter is superior to the former when the network delay is large[*3].

Control which is effective for a wider range of network delay has not been studied so far.

*1 T. Abe *et al.*, ICCE-TW, pp. 133-134, May 2018.
*2 L. Wen *et al.*, Record of 2019 Tokai-Section Joint Conference on Electrical, Electronics, Information, and Related Engineering, L1-7, Sep. 2019.
*3 L. Chen *et al.*, ICCE-TW, Sep. 2020.

Purpose

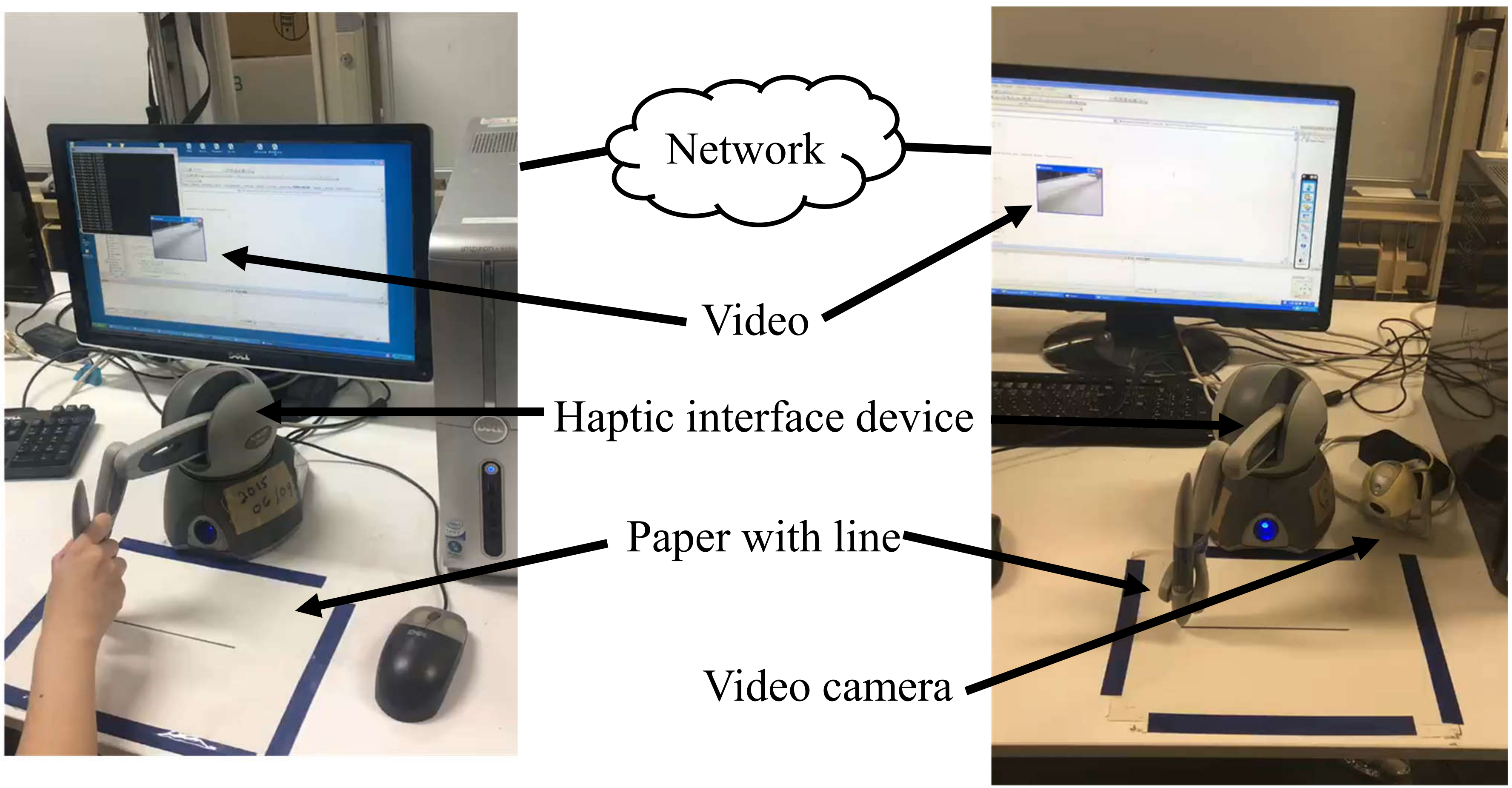
This work

- Propose a switching scheme that uses the adaptive viscosity control when the network delay is small and employs the stabilization control by viscosity when the network delay is large.
- Illustrate the effectiveness of the switching scheme in terms of the operability of haptic interface device by QoE assessment.

Remote Control Systems with Haptics

Master terminal

Slave terminal



Calculation Method of Reaction Force

Elasticity (spring) | Viscosity (damper)

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

Elasticity is force exerted by a spring, for example, when we push or pull the spring.

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

$\boldsymbol{F}_t^{(\mathrm{m})}$: 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

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

Adaptive Elasticity Control

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

$$K_s = 9/(2D + 90)$$ [*1]

D : One-way network delay between the two terminals

*1 T. Abe *et al.*, 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.

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

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

*1

D_{peak} : Peak value of optimum viscosity coefficient

v : Moving velocity

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

Stabilization Control by Viscosity

- The movement of the haptic interface device at the slave terminal is reduced by a fixed amount in order to produce viscosity.
- The control is carried out only at the slave terminal.

$$K_d = 0$$
$$\boldsymbol{S}_t^{(s)} = \boldsymbol{M}_{t-1}^{(s)} - C_d(\boldsymbol{M}_{t-1}^{(s)} - \boldsymbol{S}_{t-1}^{(s)})$$

*2

$\boldsymbol{S}_t^{(s)}$, $\boldsymbol{M}_t^{(s)}$: Position vector of slave/master terminal at time t

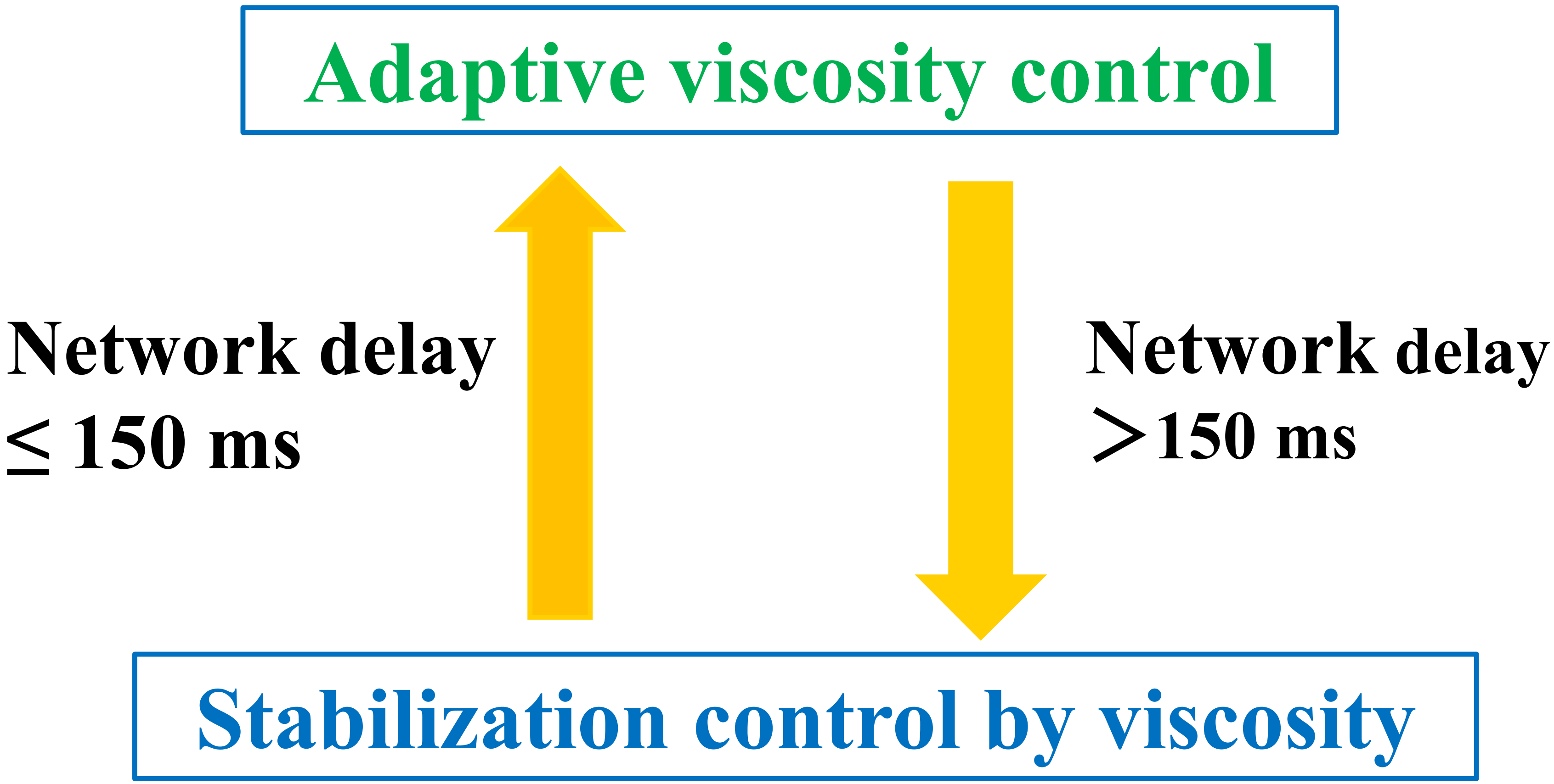
C_d : Coefficient related to viscosity

$$C_d = 0.936$$

*2

*2 L. Wen et al., Record of 2019 Tokai-Section Joint Conference on Electrical, Electronics, Information, and Related Engineering, L1-7, Sep. 2019.

Switching Scheme



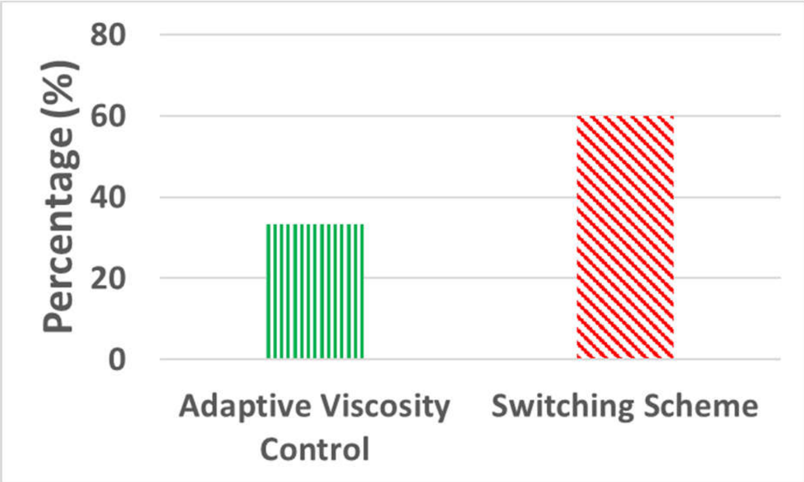
Assessment Method

- Two terminals are connected to a network emulator to produce a constant delay (called the ***additional delay***) for each packet.
- **Work**: Move the haptic interface device to right and left (the *x*-axis) along a line for 30 seconds.
- **Additional delay**: Changed after 15 seconds in four cases :

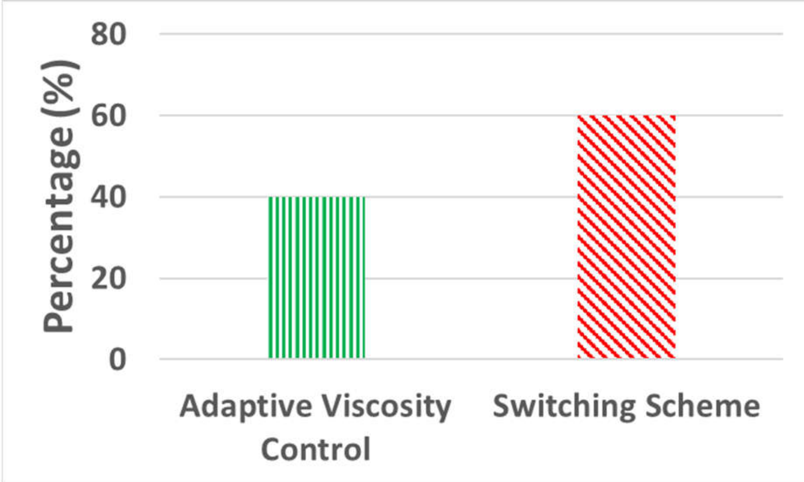
  (a) from 50 ms to 200 ms, (b) from 200 ms to 50 ms,
  (c) from 100 ms to 200 ms, (d) from 200 ms to 100 ms
- **Stimuli**: Comparison between **adaptive viscosity control** and **switching scheme**, and that between **stabilization control by viscosity** and **switching scheme** are exerted in random order for each case.
- **Judgment**: Selected one from among three answers (1: Former is better, 2: Not sure, and 3: Latter is better)
- **Subjects**: 15 (ages: between 20 and 25)

Assessment Results (1/3)

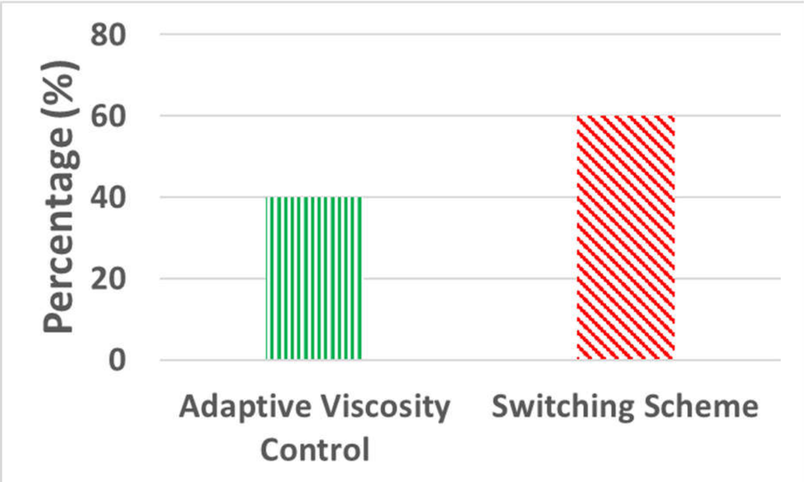
Comparison between adaptive viscosity control and switching scheme



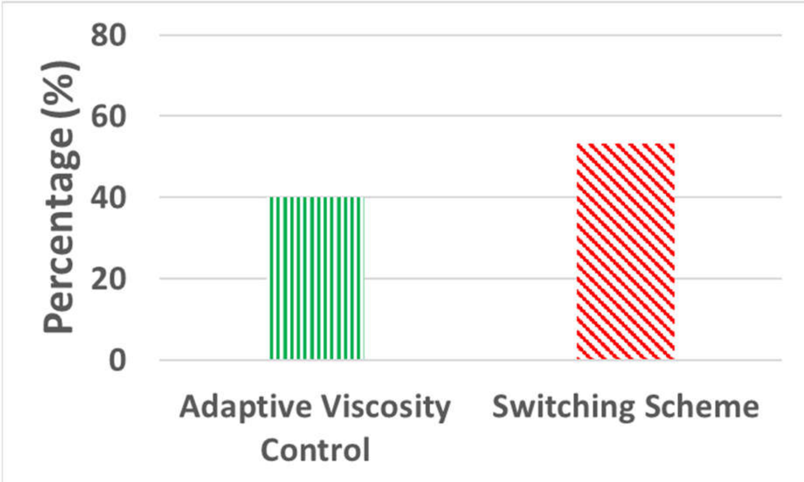
Case (a): From 50 ms to 200 ms



Case (b): From 200 ms to 50 ms



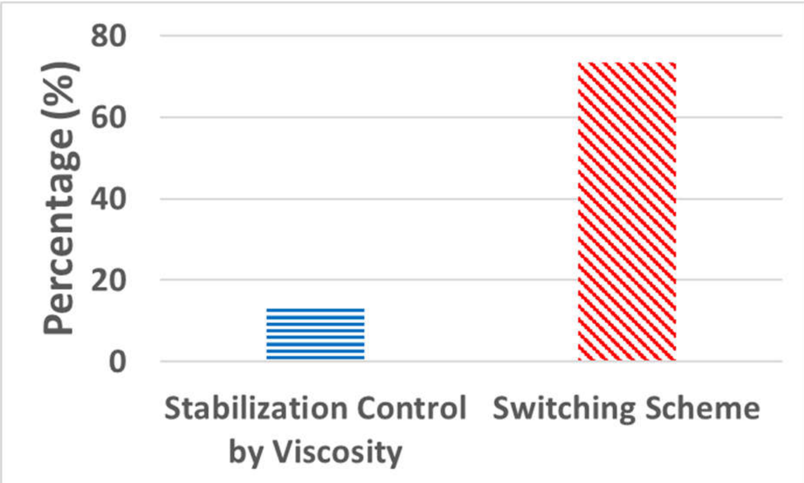
Case (c): From 100 ms to 200 ms



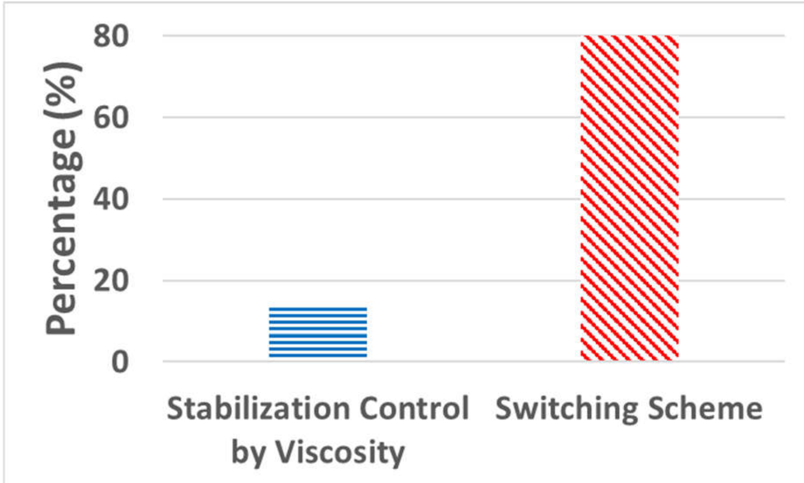
Case (d): From 200 ms to 100 ms

Assessment Results (2/3)

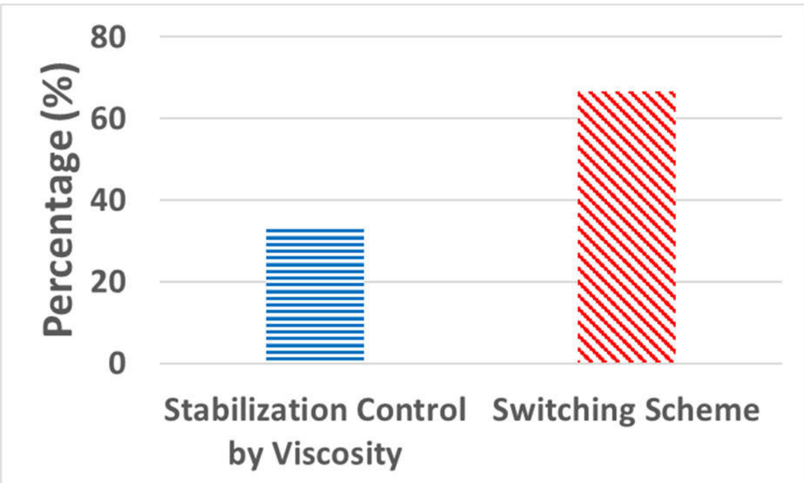
Comparison between stabilization control by viscosity and switching scheme



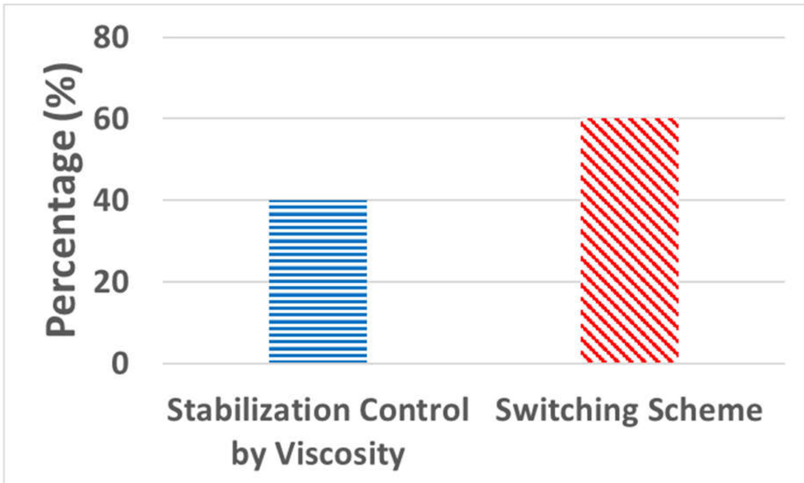
Case (a): From 50 ms to 200 ms



Case (b): From 200 ms to 50 ms



Case (c): From 100 ms to 200 ms

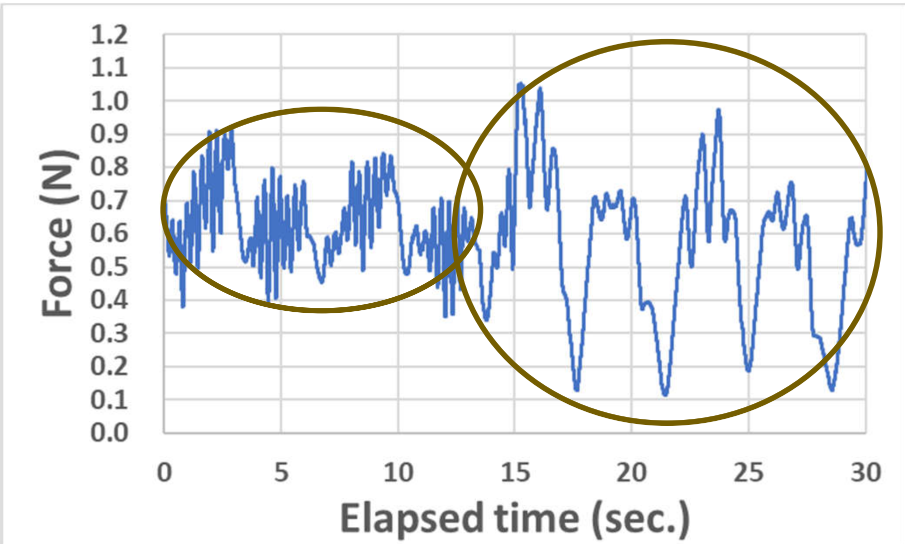


Case (d): From 200 ms to 100 ms

Assessment Results (3/3)

Additional Delay

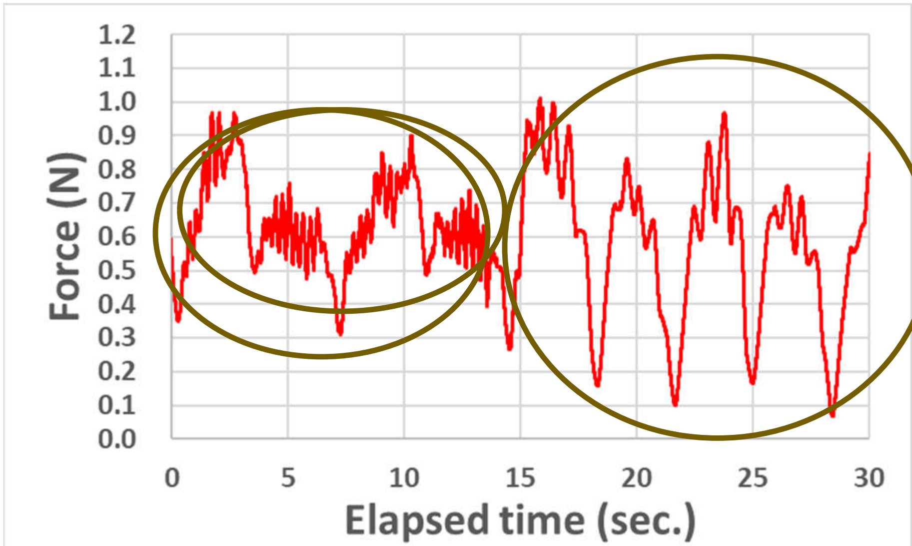
⬅ 50ms ➡ ⬅ 200ms ➡



(a) Stabilization control by viscosity

Additional Delay

⬅ 50ms ➡ ⬅ 200ms ➡



(b) Switching scheme

Conclusions and Future Work

Conclusions

- **Proposed a switching scheme in remote control system with haptics.**
- **Illustrated the effectiveness of the switching scheme in terms of the operability of haptic interface device by QoE assessment.**

Future Work

- **Plan to change C_d** (coefficient related to viscosity) **dynamically according to the network delay and the moving velocity of the haptic interface device.**