Comparison of Stabilization Control in Remote Control System with Haptics

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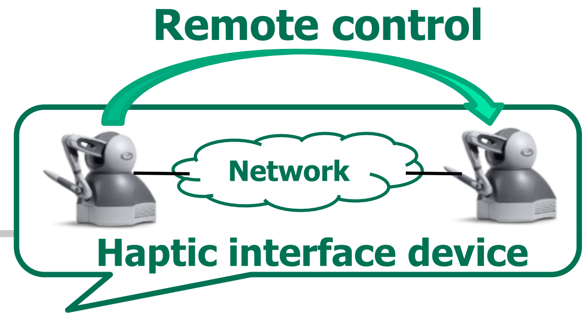
Outline

- Background
- Previous Work
- Purpose
- Remote Control System with Haptics
- Stabilization Control
- Assessment Method
- Assessment Results
- Conclusions and Future Work

Background



Remote control system with haptics in which a user can remotely <u>operate **a haptic interface device** by using **another haptic interface device**</u> 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

Relationships between two types of control to suppress unstable phenomena have not been clarified so far.

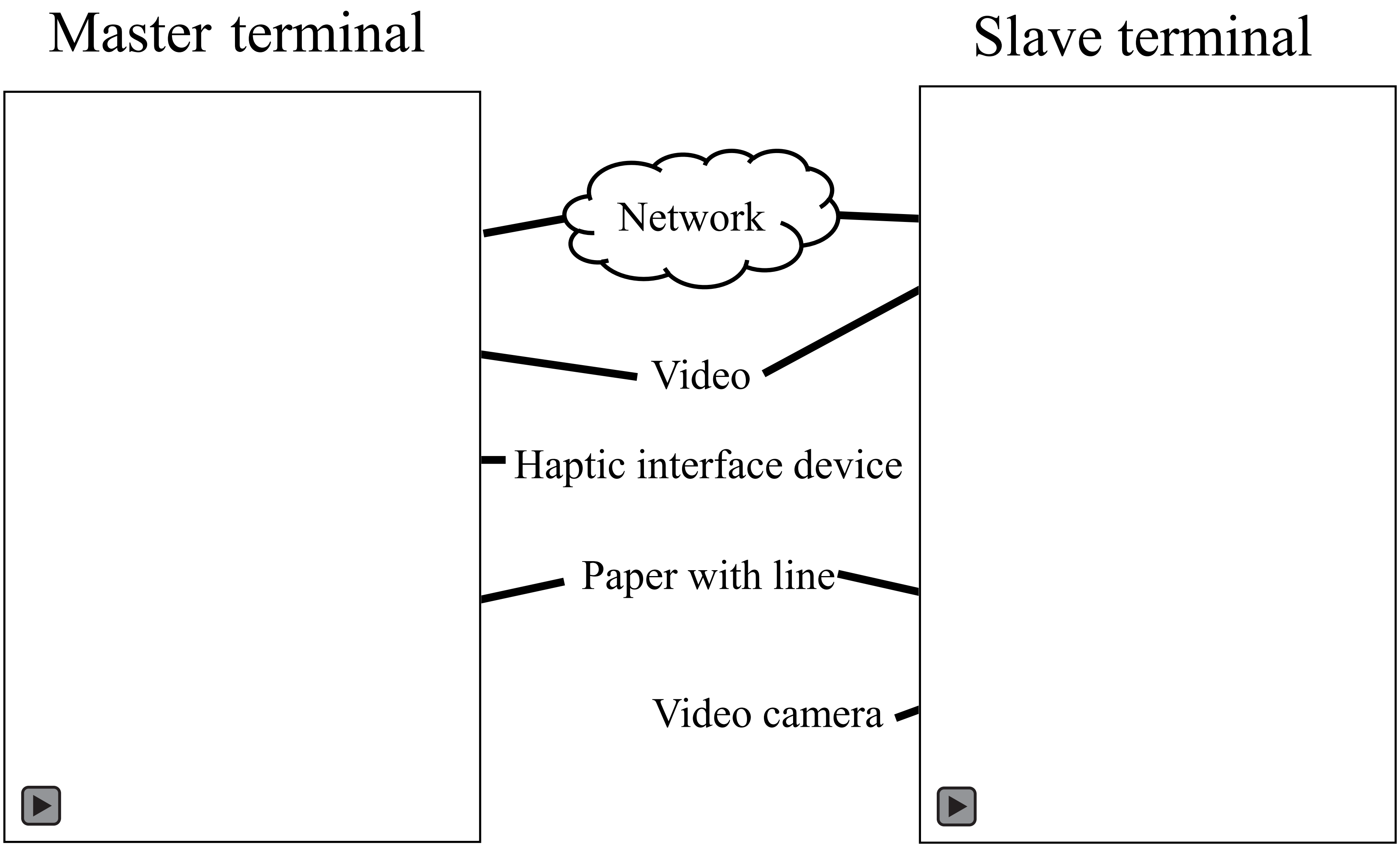
*1 T. Abe *et al*., ICCE-TW, pp. 133-134, May 2018.
*2 L. Wen *et al*., Record of 2019 Tokai-Section Joint Conference on Electrical, Electronics, Information, and Related Engineering, L1-7, Sep. 2019.

Purpose

This work

- **Comparison between the adaptive viscosity control and the stabilization control by viscosity by QoE assessment**
- **Carrying out the adaptive elasticity control together with the above control to reduce strong force in the assessment**

Remote Control Systems with Haptics



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

To reduce strong force

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

To suppress unstable phenomena

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

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

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

To suppress unstable phenomena

The movement of the haptic interface device at the slave terminal is reduced by a fixed amount proportional to the position difference in order to produce viscosity.

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

*2

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

C_d : Coefficient related to viscosity

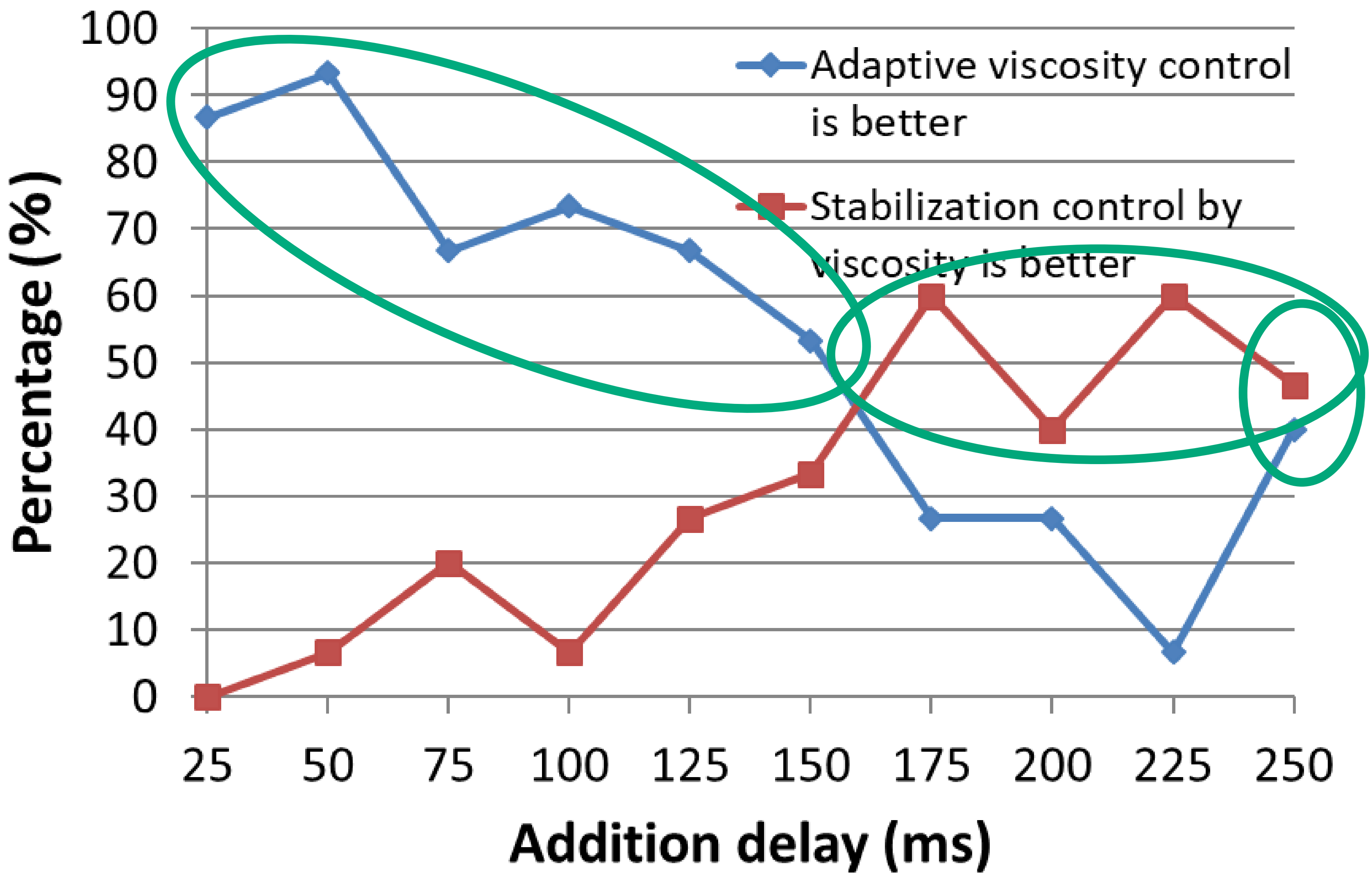
$C_d = 0.936$ *2

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

Assessment Method

- **Assessment system**: Mater and slave terminals are connected to a network emulator to produce a constant delay (called the ***additional delay***) for each packet.
- **Work**: Each subject moves the haptic interface device to right and left (the *x*-axis) along a line with length of 16 cm for 30 seconds.
- **Additional delay**: 25 ms to 250 ms at intervals of 25 ms (presented in random order for each subject)
- **Stimuli**: Adaptive viscosity control and stabilization control by viscosity are exerted in random order for each additional delay.
- **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



Conclusions and Future Work

Conclusions

- **Compared two types of stabilization control for remote control system with haptics by QoE assessment.**
- **If the network delay is small, the adaptive viscosity control is superior to the stabilization control by viscosity; otherwise, the latter is better.**

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**
- **Switch the two types of control dynamically according to the network delay**