# Effect of Stabilization Control on Cooperative Work between Remote Robot Systems with Force Feedback

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# Background (1/2)

- **Remote robot systems with force feedback have been actively researched.**

  **Users remotely control robot arms having force sensors by using haptic interface devices.**

- **Many researchers have paid attention to cooperative work among multiple remote robot systems recently.**

**It is possible for users to perceive the shape, weight, and softness of a remote object with force feedback.**

**The efficiency and accuracy of work are expected to be improved largely.**

# Background (2/2)

**When force information is transmitted over the Internet, which does not guarantee the quality of service (QoS)**

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

**Quality of Experience (QoE) degradation**

**Instability phenomena**

- **Stabilization control**
- **QoS control**

# Previous Work

*1 Y. Toyoda *et al*., IEICE Technical Report, CQ2018-9, Apr. 2018.
*2 Y. Toyoda *et al*., IEEE ICECE, Dec. 2018.

- **Influence of network delay on the efficiency of cooperative work between a user and a remote robot system with force feedback was investigated[*1].**
  - ✓ **The average time of work increases as the network delay becomes larger.**
- **The efficiency of cooperative work between two remote robot systems with force feedback was clarified[*2].**
- **Comparison of the efficiency was made[*2].**
  - ✓ **The average times of the two types of work are roughly the same.**
  - ✓ **The force between the systems is larger than that between the user and system.**

**Problem** **Both experiments have instability phenomena when the network delay is large.**

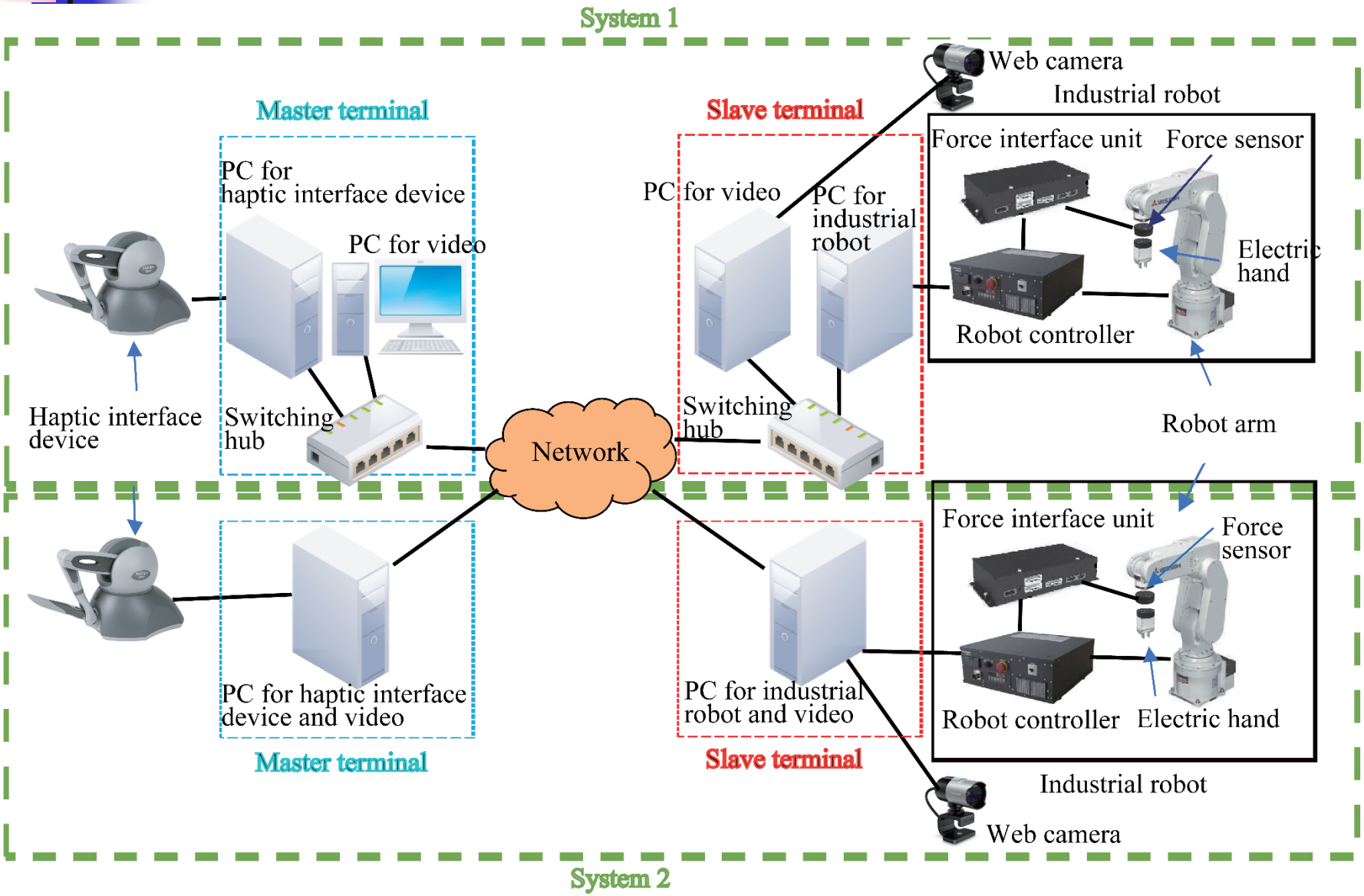
*3 Q. Qian *et al.*, IEICE Global Conference, BS-2-14, Mar. 2018.

# Purpose

## This work

- **We apply the switching control[*3] as stabilization control to the remote robot system with force feedback.**
- **We investigate the effect of the switching control on hand delivery of an object between the two systems.**
- **We examine the influence of network delay on the hand delivery by experiment.**

# Remote Robot Systems with Force Feedback



# Switching Control*3

*3 Q. Qian *et al.*, IEICE Global Conference, BS-2-14, Mar. 2018.
*4 T. Rikiishi *et al.*, IEICE Society Conference, BS-7-21, Sep. 2017.
*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

- **Carrying out the stabilization control by viscosity*4 for soft objects and the reaction force control upon hitting *5 for hard objects.**

***In a preliminary experiment, we found that the stabilization control by viscosity is effective for soft objects, and the reaction force control upon hitting is effective for hard objects.***

**Judgement of Softness**

**If the increment of reaction force for an object exceeds a threshold, the object is judged as a hard object.**

## Stabilization Control by Viscosity

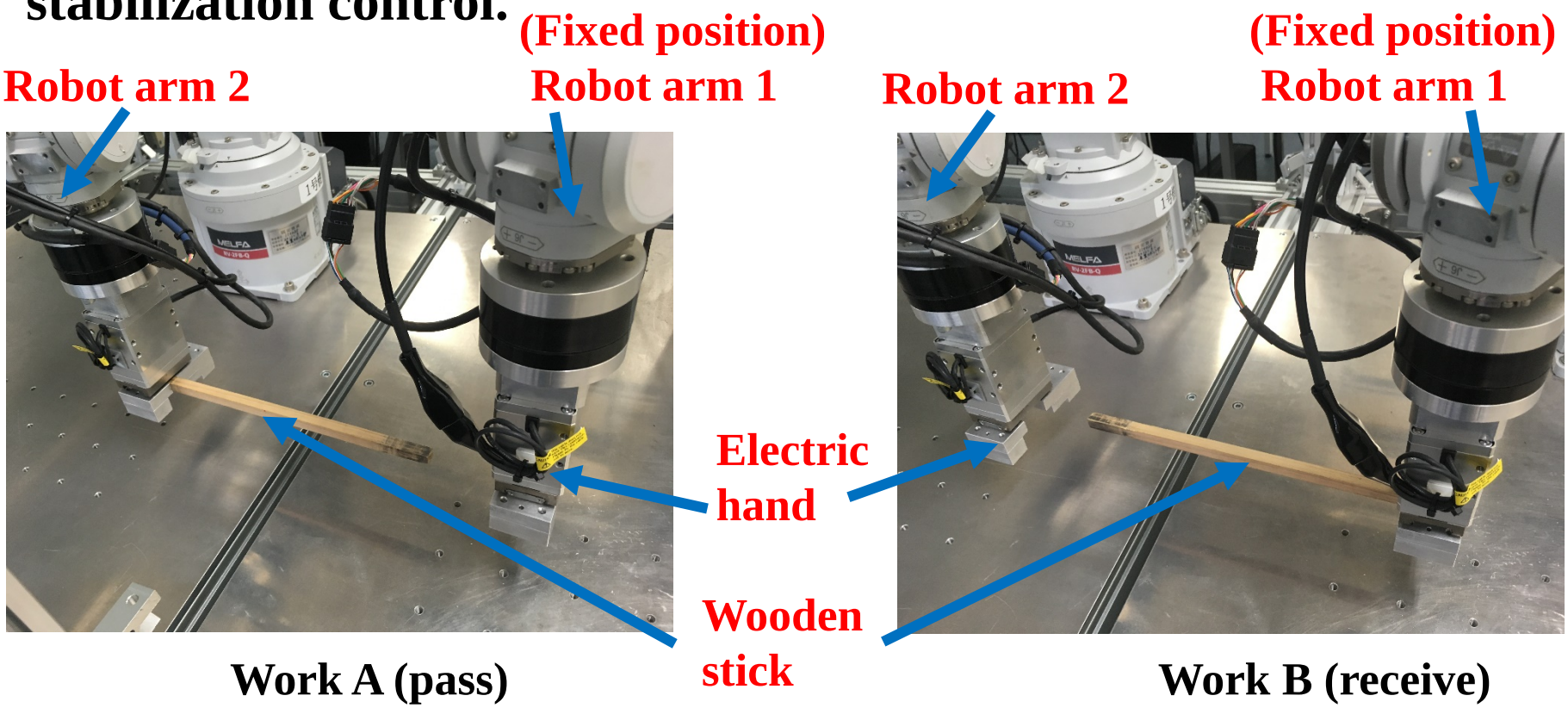
- **The instability phenomenon can be suppressed by viscosity.**
- **We generate viscosity by decreasing the movement distance of the robot arm by a certain amount proportional to the position difference.**

## Reaction Force Control upon Hitting

- **The reaction force outputted by the haptic interface device is gradually increased to avoid the jump-up of the robot arm when the arm hits hard objects.**

# Experiment Method (1/2)

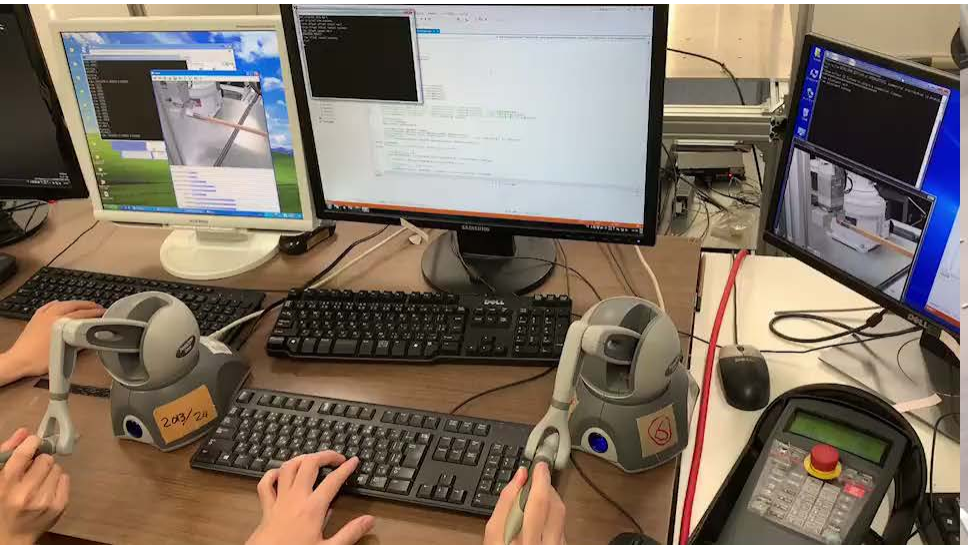
- Deal with two types of cooperative work (*work A* and *work B* ) in which a wooden stick with lengths of 30 cm was hand-delivered between the two robot arms under the switching control and no stabilization control.

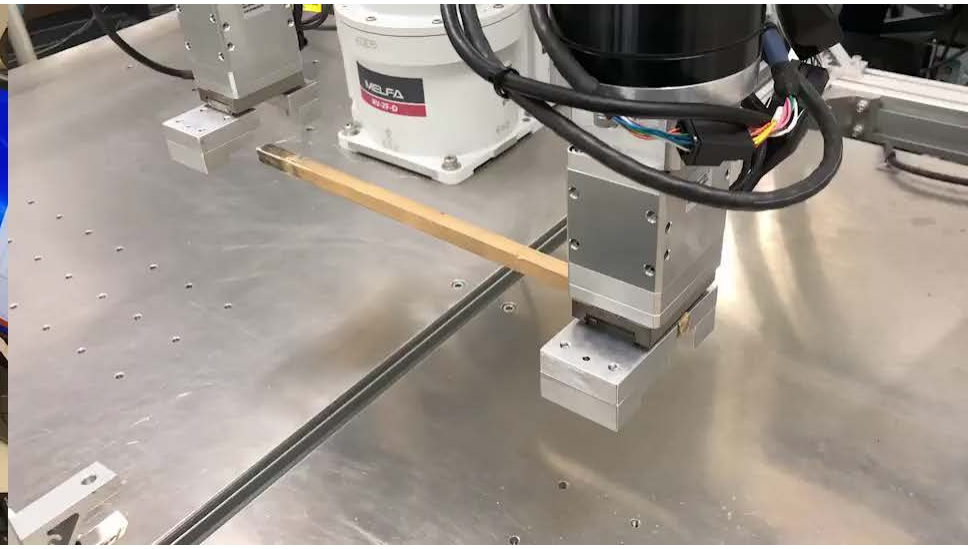


# Experiment Method (2/2)

- We produced the additional delay which was varied from 0 ms to 200 ms at intervals of 100 ms by using a network emulator.
- The additional delays for systems 1 and 2 were selected in random order.
- We carried out the experiments 10 times for each combination of additional delays in work A and work B.
- The average work time was measured
  - ✓ The average time from the moment the work is started until the instant the stick is hand-delivered.
- One of the authors operated robot arm 2, and another person did robot arm 1.

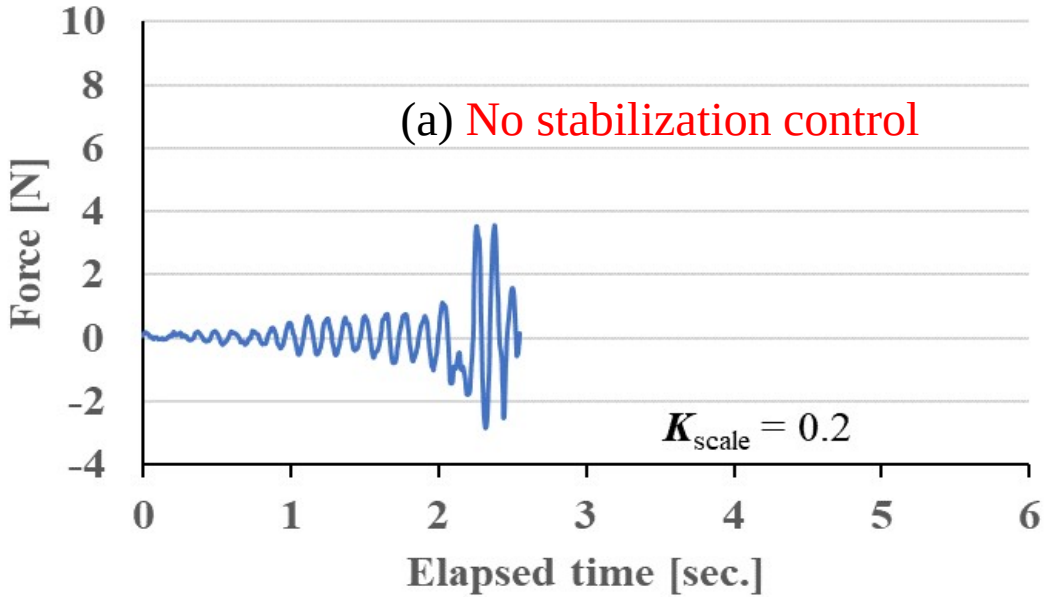
# Demo video

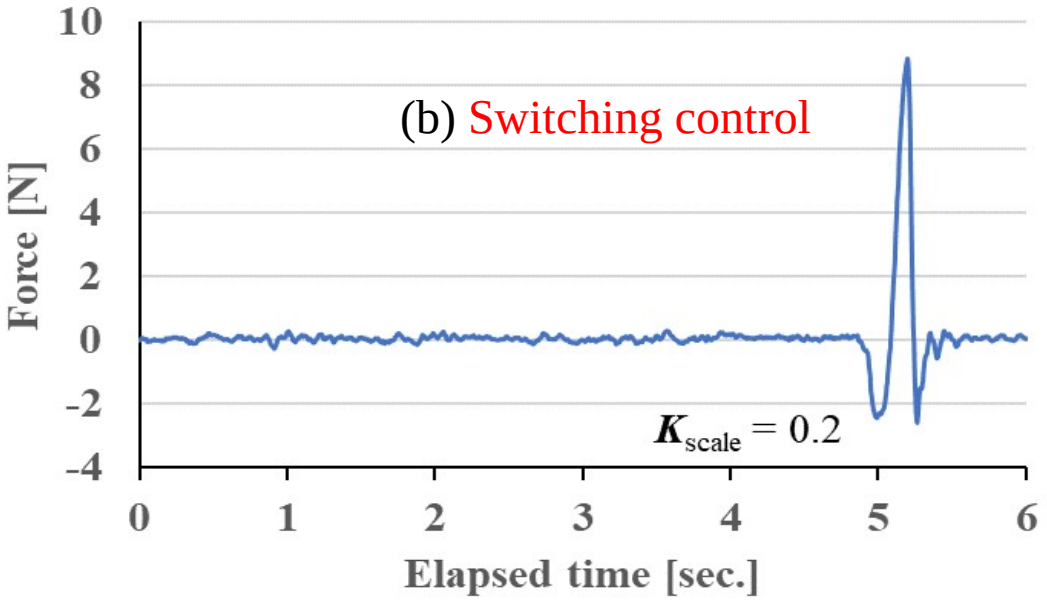





**Cooperative work:** **Work B (receive)**
**Additional delay:** **0 ms**
**Stabilization control:** **Switching control**

# Experiment Results (1/2)

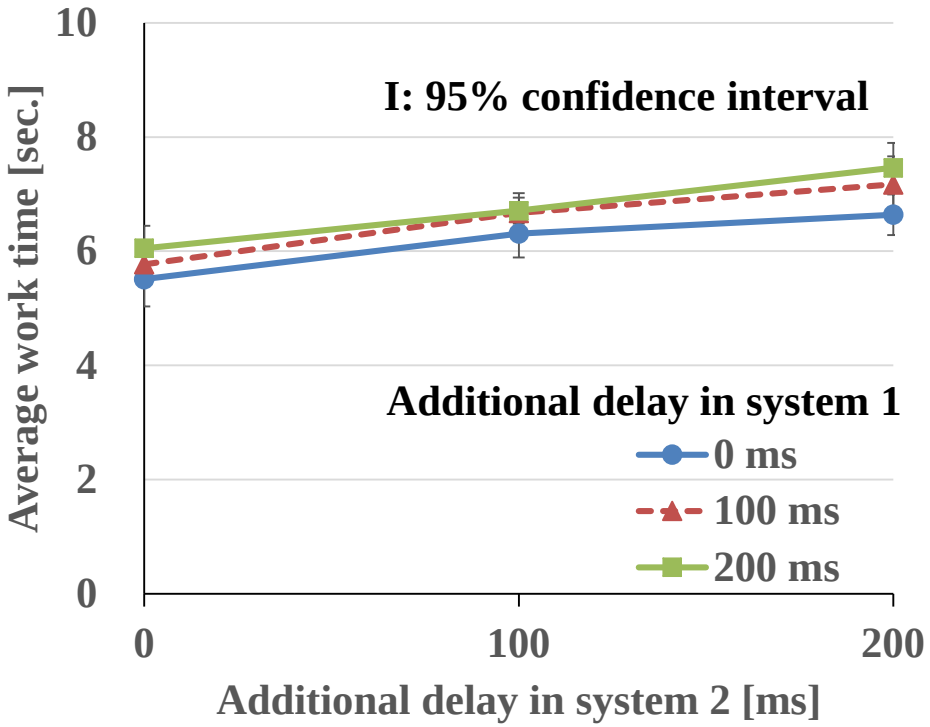


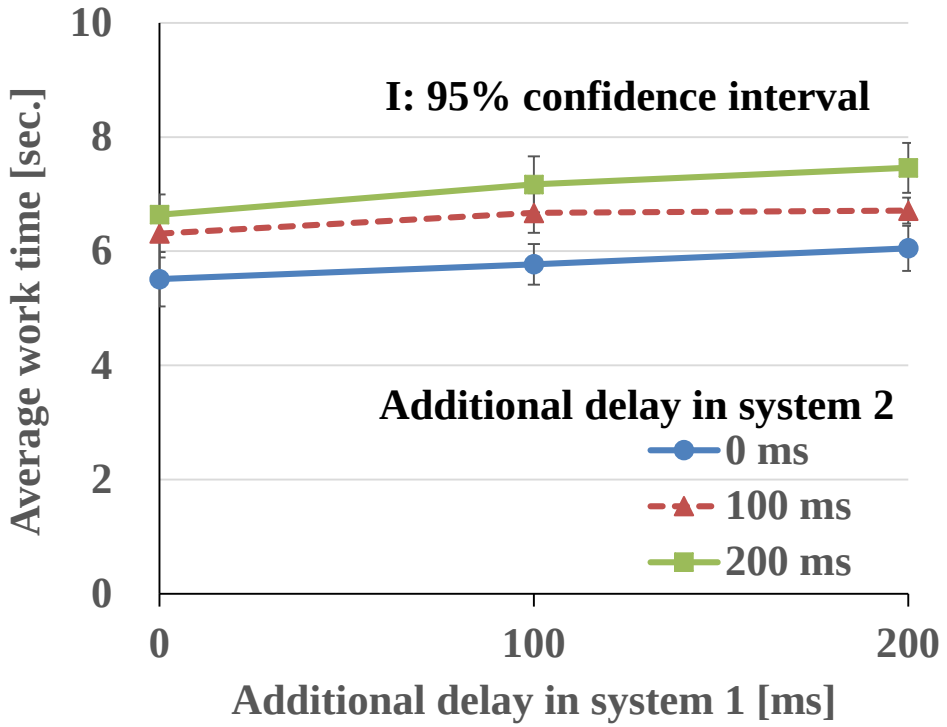




$K_{scale}$ :
**Mapping ratio about scale of force between the haptic interface device and the robot arm**

**Work B (receive)**

# Experiment Results (2/2)




**Work B (receive)**

# Conclusion

- **We investigated the effect of the switching control on hand delivery of an object between the two remote robot systems with force feedback by experiment.**
- **We also examined the influence of the network delay on the hand delivery of the object.**

- **The switching control is effective for the cooperative work.**
- **The average work time increases as the network delay becomes larger.**

*6 Y. Toyoda *et al*., IEICE, 2018-90, Jan. 2019.

# Future Work

- **Study of QoS control to reduce the average work time[*6]**
- **Dealing with other types of cooperative work under the switching control**