Effects of Adaptive Δ-Causality Control for Cooperation between Remote Robot Systems with Force Feedback by Using Master-Slave Relation

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Background

- ✓ **Remote robot systems with force feedback have actively been researched.**
- ✓ **It is possible to transmit the information about the shape, weight, and softness of a remote object by using haptic interface devices.**
- ✓ **The efficiency and accuracy of work can largely be improved by using the remote robot system with force feedback.**

However, when we transmit haptic information over the Internet, which does not guarantee QoS (Quality of Service)

Network delay, delay jitter, and packet loss →

・QoE (Quality of Experience) degrades
・Instability phenomena occur.

↓

QoS control and stabilization control

Problems (1/2)

*1 E. Taguchi *et al.*, IEICE General Conference, B-11-17, Mar. 2018.

Previous work

- ✓ **By using the two remote robot systems (with the equal relationship) with force feedback, we investigate the influence of the network delay on the work of carrying one object cooperatively[*1].**

- ✓ **The network delay damages the work efficiency.**
- ✓ **The effect of the QoS control has not been clarified quantitatively.**
- ✓ **As another relation, the master-slave relation is also important.**
- ✓ **The effect of the systems by using master-slave relation is not investigated.**

Problems (2/2)

*2 Y. Hara *et al*., in Proc. The 11th Annual Work shop on Net Games, Nov. 2012.

Preliminary experiment

- ✓ **Performed the collaborative work by using the two remote robot systems with a master-slave relation.**
- ✓ **Investigated the influence of the network delay between the systems on the work.**

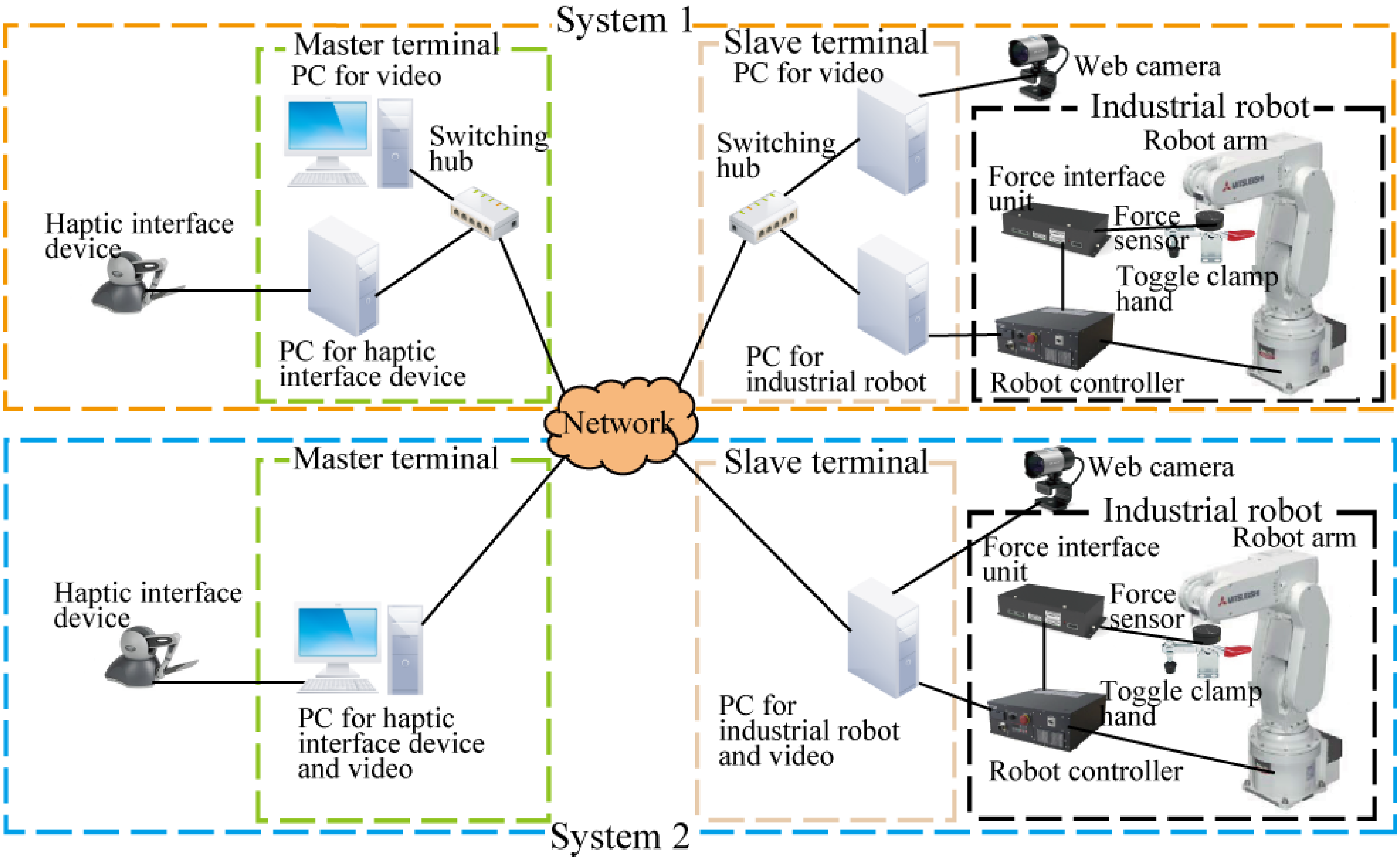
- ✓ **As the network delay becomes larger, the work efficiency deteriorates.**
- ✓ **We can use the adaptive Δ-causality control [*2], which adjusts the output timing of the position information among the systems dynamically according to the network delay, as QoS control.**
- ✓ **The effect of the adaptive Δ-causality control has not been clarified quantitatively.**

Purpose

This work

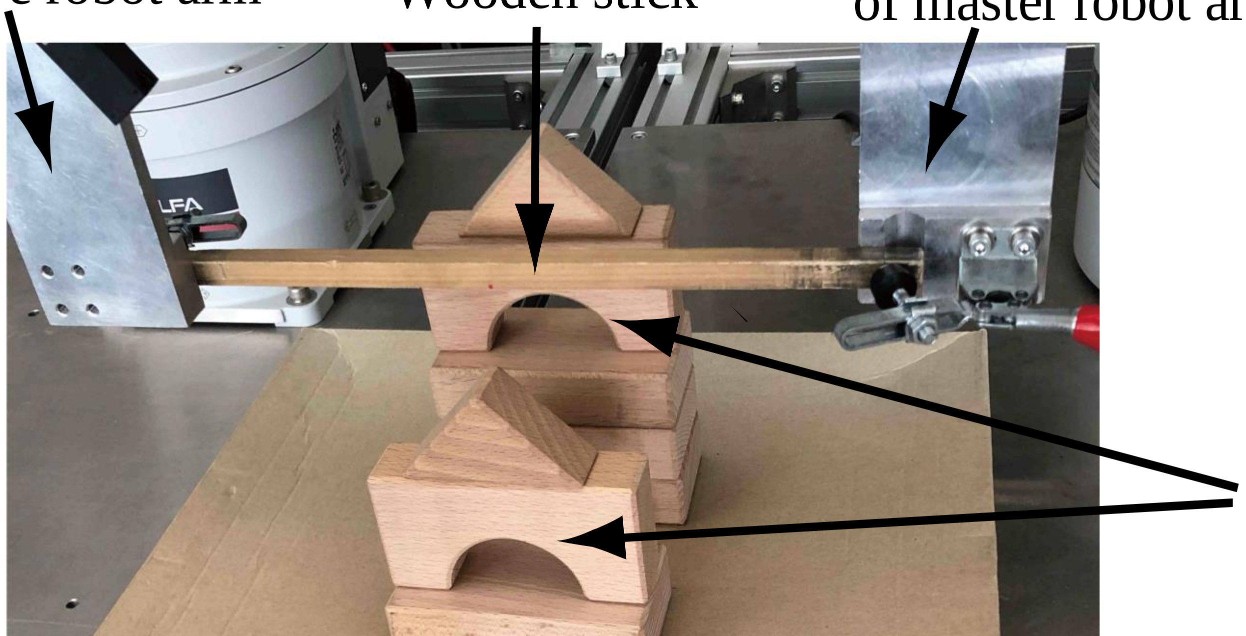
- ✓ **Apply the adaptive Δ-causality control to the systems.**
- ✓ **Investigate the influence of the network delay on the collaborative work (carrying object together).**
- ✓ **Investigate the effect of the control by experiment.**

Remote robot systems with force feedback

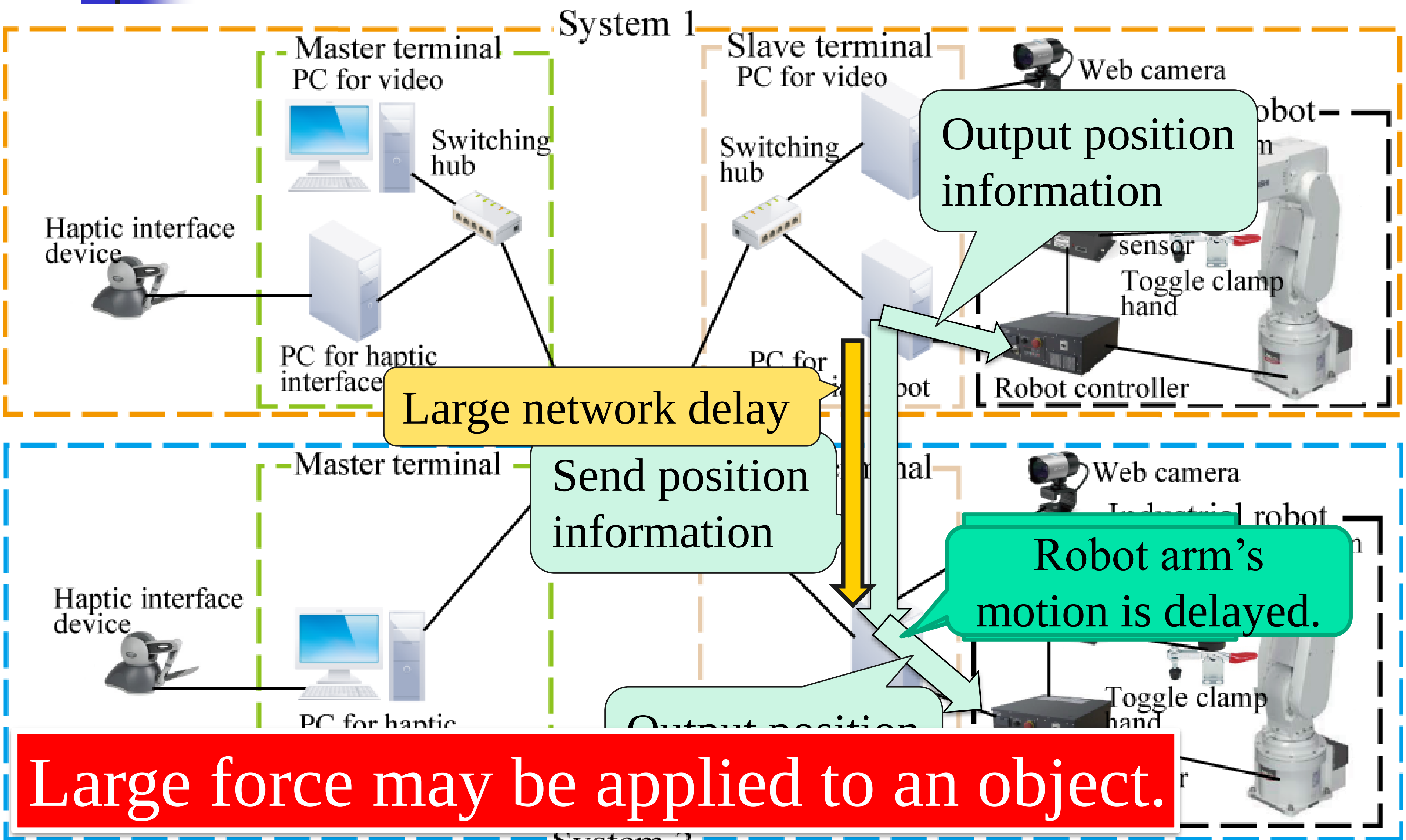


Carrying Object Together

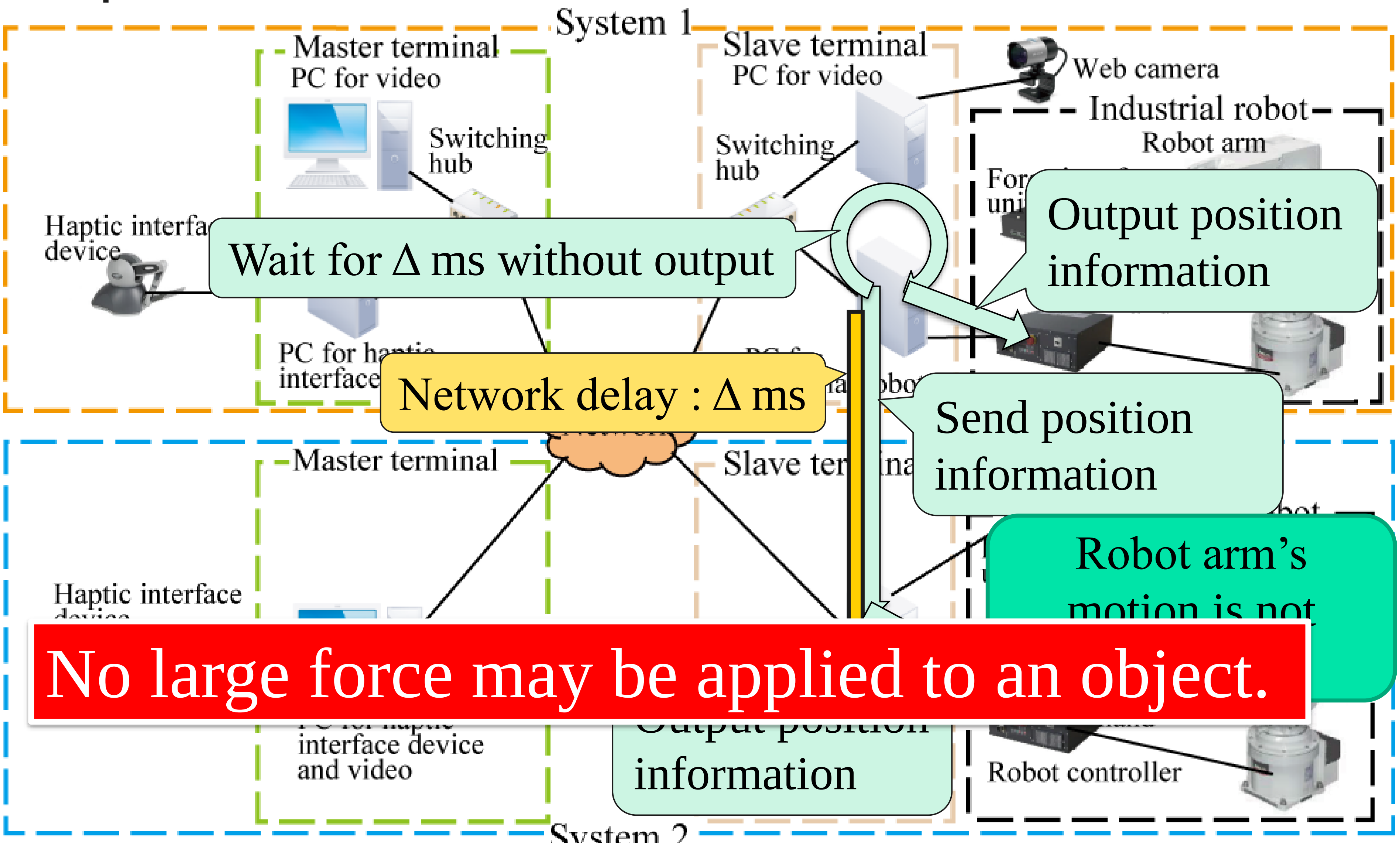
- ✓ **Move a wooden stick together by the two industrial robot arms while watching video.**
- ✓ **In order to move the robot arms in almost the same way always, we push and drop the uppermost block of the piled building blocks by moving the robot arms together with the force feedback devices.**



Master - slave relation



Adaptive Δ-causality control (1/2)



No large force may be applied to an object.

Adaptive Δ-causality control (2/2)

*2 T. Abe *et al.*, Journal of IEICE, vol. 91, no. 2, Feb. 2008.

- **Δ is set to the smoothed network delay D_t.**

$$\begin{cases} D_0 = d_0 \\ D_t = \alpha D_{t-1} + (1-\alpha) d_t \quad (t \geq 1) \end{cases}$$

Smoothing coefficient $\alpha = 0.998$[*2]

d_t : Network delay at time *t*

- **Information received after generation time + Δ is discarded as old and useless information.**

Experiment method

- ✓ We generated a constant delay (called the *additional delay*) for each packet transmitted between the two systems by a network emulator (NIST Net).

- ✓ We measured the force sensed by the force sensor and the robot arm position in the two cases:

Control : the adaptive Δ-causality control was performed.

No control : the control was not exerted.

Demo video

Network delay between robots : 200 ms

Slave robot

Master robot

No control

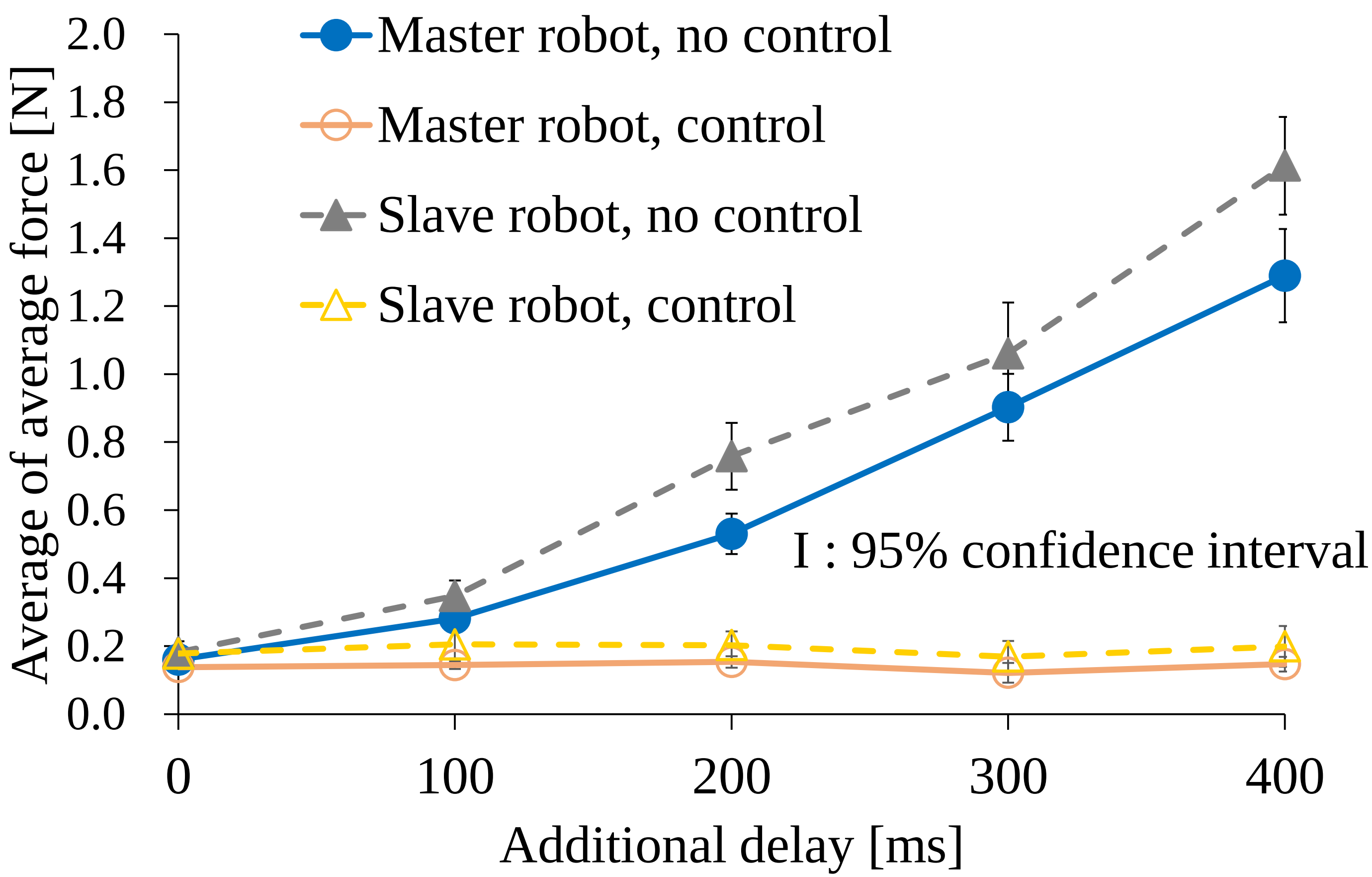
Slave robot

Master robot

Control

Experiment results (1/2)

Average of average force in the x-axis of each robot

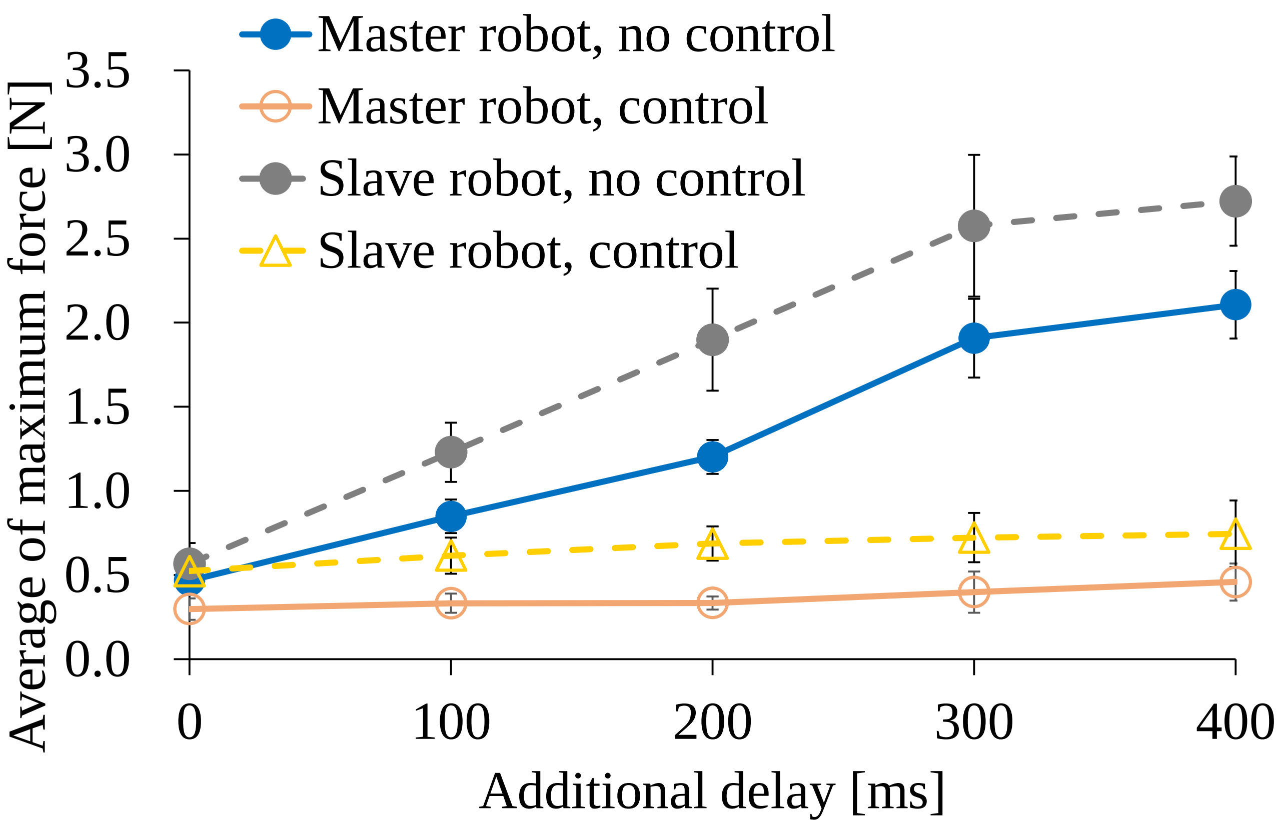


Average force : ***Time average of absolute force measured during 15 seconds***

Average of average force : ***Mean of 10-time average force***

Experiment results (2/2)

Average of maximum force in the x-axis of each robot



Conclusion

- ✓ We applied the adaptive Δ-causality control to the cooperative work of the two remote robot systems with force feedback by using master-slave relation.

- ✓ We investigated the effect of the control and influence of the network delay.

- ✓ The influence of network delay can greatly be alleviated by the control.

Future work

*3 P. Huang *et al*., IEICE, CQ2017-79, Nov. 2017

- ✓ **Switch the master-slave relationship dynamically according to the network delay in each system.**
- ✓ **Apply the control to the two remote robot systems with the equal relationship and investigate the effect of the control.**
- ✓ **Apply stabilization control[*3].**