Influences of Network Delay on Cooperative Work between Remote Robots with Force Feedback

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Outline

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Background (1/3)

Remote robot system with force feedback has actively been studied.

It is possible for users to feel the shape, softness, surface smoothness, and weight of a remote object by using a haptic interface device (i.e., force feedback).

⇩

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

Background (2/3)

When information about force is transmitted over a network such as the Internet, which does not guarantee QoS (Quality of Service)

Network delay, delay jitter and packet loss

- Degradation of QoE (Quality of Experience)
- Instability phenomena

QoS control and stabilization control

Background (3/3)

We cannot carry out the control efficiently if influences of network delay in work are not clarified enough.

We should investigate the influences of network delay on work.

Problem

*1 K. Kanaishi *et al.*, ICTCE, Nov. 2019.

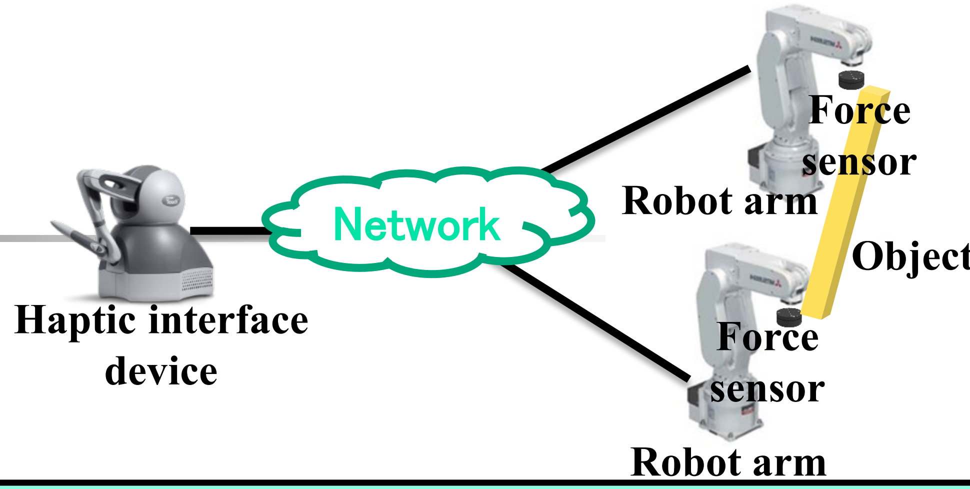
Previous Study*1

- Cooperative work (carrying an object together) by using two remote robot systems was conducted with a master-slave relation, and the adaptive Δ-causality control is performed.
- The control sends the position information of the robot in the master system to the robot in the slave system and delays its transmission to the master system by the network delay.

➡ The robot movements in the master and slave systems are synchronized with each other.

We can also synchronize the robot movements by sending the position information of one haptic interface device to the two robots.

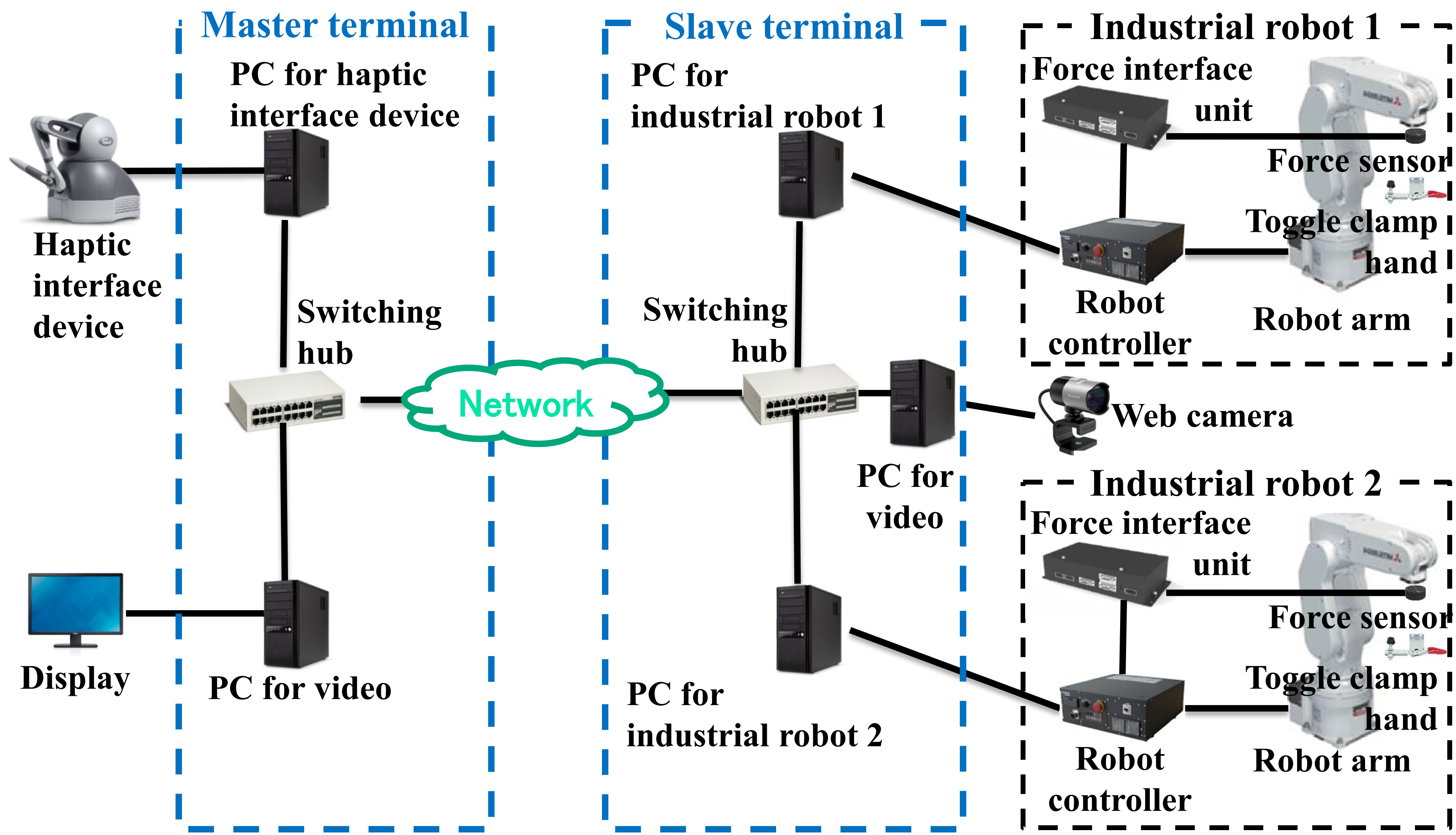
Purpose



This Study

- **We investigate influences of the network delay on cooperative work of carrying an object together.**
- **The cooperative work is performed by two robots which are remotely operated with one haptic interface device.**
- **We compare two calculation methods of reaction force outputted though the haptic interface device because there are two force sensors.**
  - ✓ **Calculated from force information sensed by both force sensors**
  - ✓ **Calculated from force information sensed by one force sensor**

Remote Robot System with Force Feedback



Calculation of reaction force (1/2)

*1 K. Kanaishi *et al.*, ICTCE, Nov. 2019.

Reaction force outputted at master terminal

We handle two calculation methods of reaction force because the system has two force sensors.

✓ **Uses force information sensed by both force sensors**

$$\boldsymbol{F}_t^{(\mathrm{m})} = K_{\mathrm{scale}} \frac{\boldsymbol{F}_{t-1}^{(s_1)} + \boldsymbol{F}_{t-1}^{(s_2)}}{2} \qquad \textbf{(2)}$$

$\boldsymbol{F}_t^{(\mathrm{m})}$: **Reaction force outputted at time t (> 0)**

$\boldsymbol{F}_t^{(S_1)}, \boldsymbol{F}_t^{(S_2)}$: **Force received from PC for industrial robot 1 and PC for industrial robot 2 at time t (> 0)**

$K_{\mathrm{scale}} = 0.5^{*1}$

Calculation of reaction force (2/2)

*1 K. Kanaishi *et al.*, ICTCE, Nov. 2019.

Reaction force outputted at master terminal

We handle two calculation methods of reaction force because the system has two force sensors.

✓ **Uses force information sensed by one force sensors**

$$\boldsymbol{F}_t^{(\mathrm{m})} = K_{\mathrm{scale}}\,\boldsymbol{F}_{t-1}^{(\mathrm{s}_2)} \qquad (3)$$

$\boldsymbol{F}_t^{(\mathrm{m})}$: **Reaction force outputted at time t (> 0)**

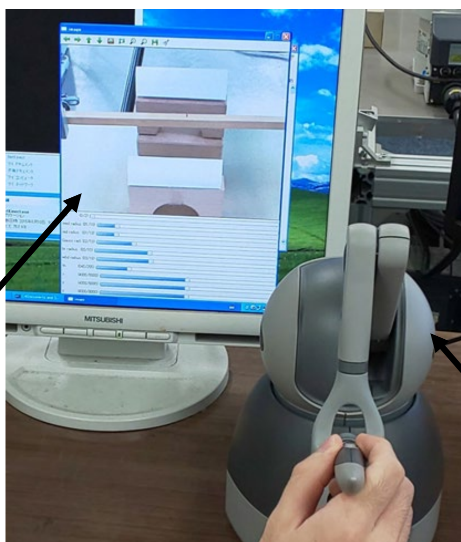
$\boldsymbol{F}_t^{(\mathrm{S}_2)}$: **Force received from PC for industrial robot 2 at time t (> 0)**

$K_{\mathrm{scale}} = 0.5$ [*1]

Experiment Method (1/3)

- **A user conducted cooperative work of carrying a wooden stick together with the two robot arms.**
- **To move the stick in almost the same way, building blocks and paper blocks were piled up ahead and behind the initial position of the stick, and touched at almost the same velocity.**

Video



Haptic interface device

Master terminal

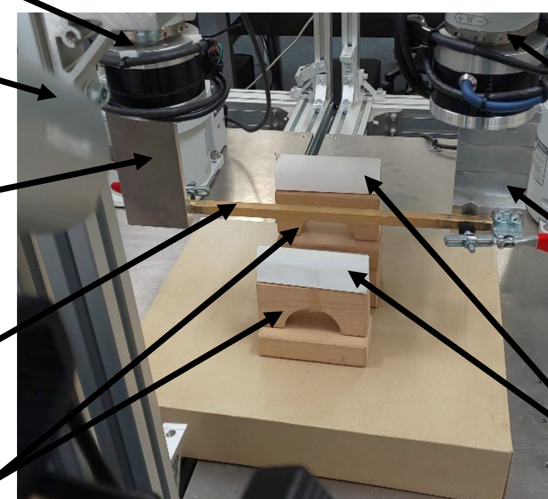
Robot arm 2

Web camera

Toggle clamp hand

Wooden stick

Building block



Robot arm 1

Toggle clamp hand

Paper block

Slave terminal

Experiment Method (2/3)

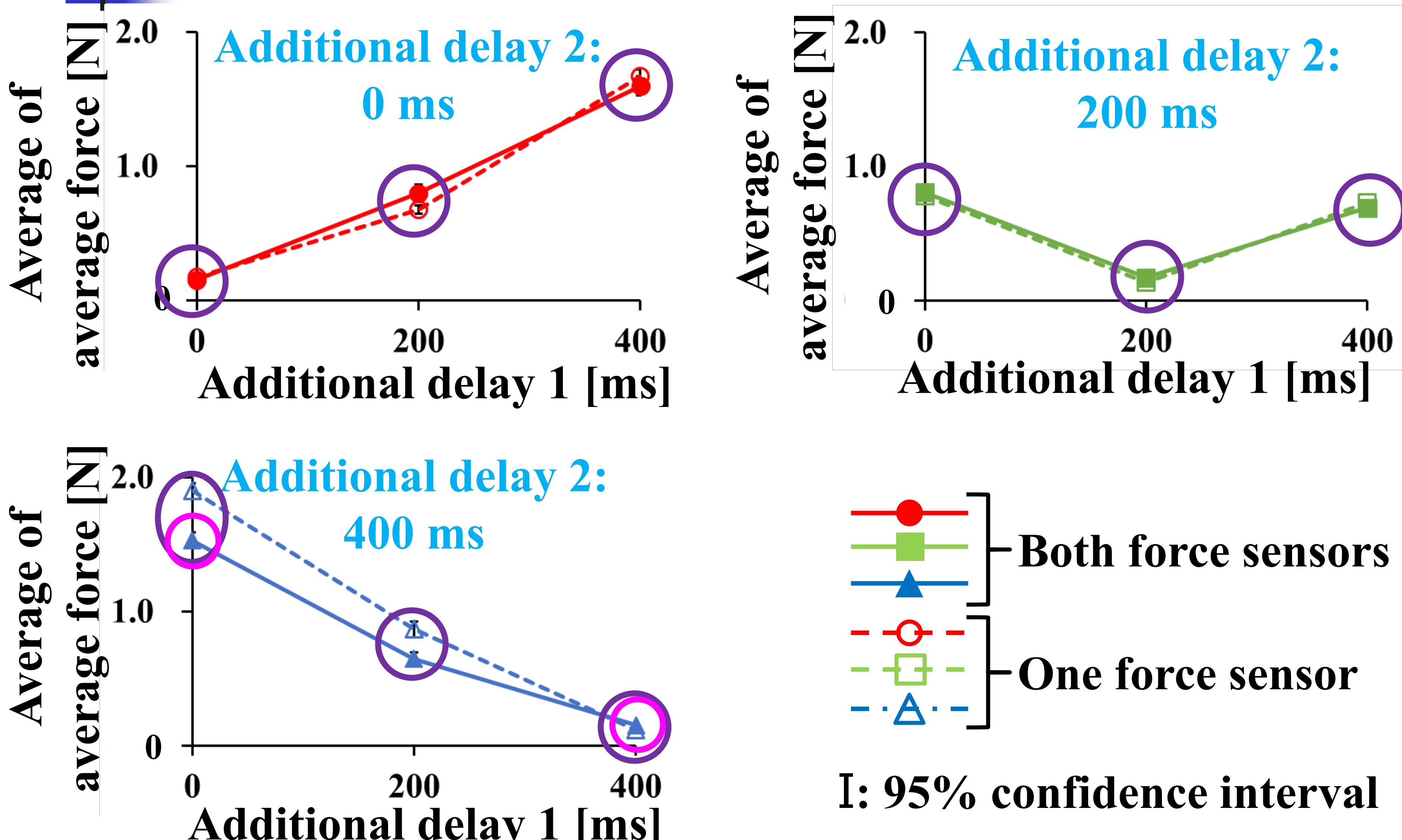
- **We generated a constant delay for each packet transmitted between the master and slave terminals by a network emulator.**
  - **The constant delay between PC for haptic interface device and PC for industrial robot 1 (called the *additional delay 1*): 0 ms, 200 ms, 400 ms**
  - **The constant delay between PC for haptic interface device and PC for industrial robot 2 (called the *additional delay 2*): 0 ms, 200 ms, 400 ms**

- **The reaction force is calculated in two cases:**
  - **Uses both force sensors**
  - **Uses one force sensor**

Experiment Method (3/3)

- **We carried out the experiment 10 times.**
- **We measured the force applied to the stick during the work and obtained the average absolute force.**
- **We calculated the average of the measure for the 10 times (called the *average of average force*).**

Experimental Results (1/2)



Experimental Results (2/2)

Reaction force: Both force sensors

Additional delay 1: 0ms
Additional delay 2: 400ms

Robot arm 2

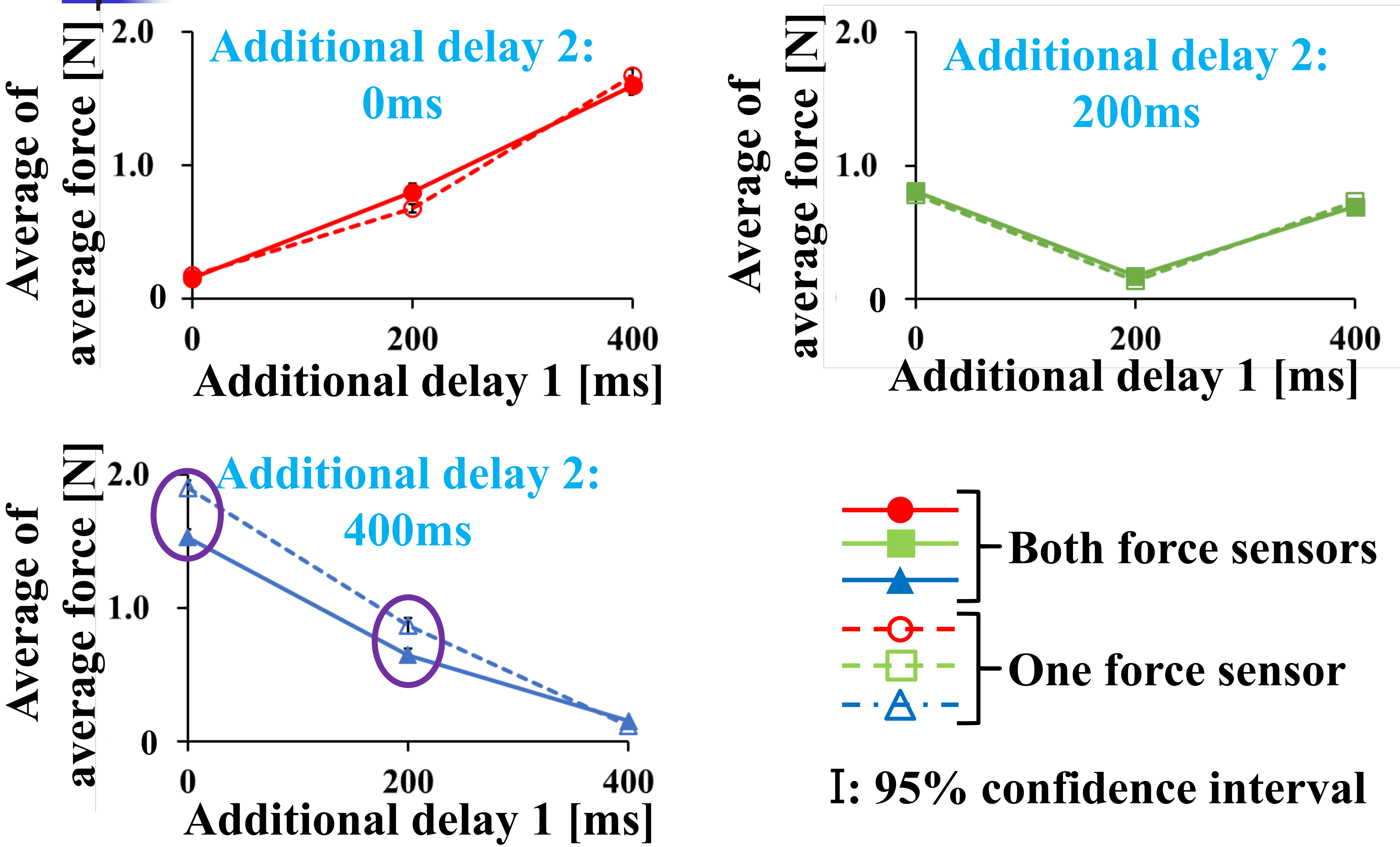
Robot arm 1

Additional delay 1: 400ms
Additional delay 2: 400ms

Robot arm 2

Robot arm 1

Experimental Results (1/2)



Conclusion and Future Study

*1 K. Kanaishi *et al*., ICTCE, Nov. 2019.
*2 P. Huang *et al*., IJCNS, July 2019.

Conclusion

- We conducted cooperative work of carrying a wooden stick together by the two robots, and we investigated influences of network delay on the cooperative work.

⇒ The force applied to the object is large when the difference between network delays for each robot is large.

Future Study

- Carry out QoS control such as the adaptive Δ-causality control[*1] to alleviate the influence of the network delay
- Exert the stabilization control with filters[*2] to avoid unstable phenomena