Influence of Change in Communication Quality on Work between Remote Master-Slave Robot Systems with Force Feedback

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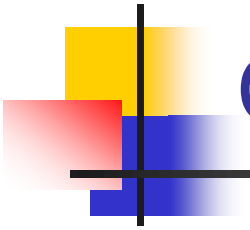

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- Robot Movement Control Using Position information
- Robot Movement Control Using Force information
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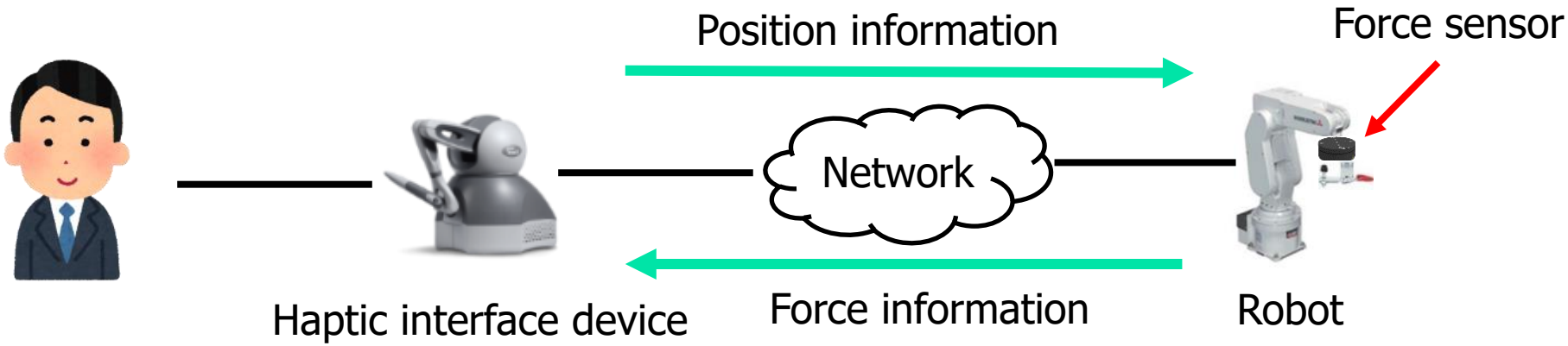
Background (1/3)

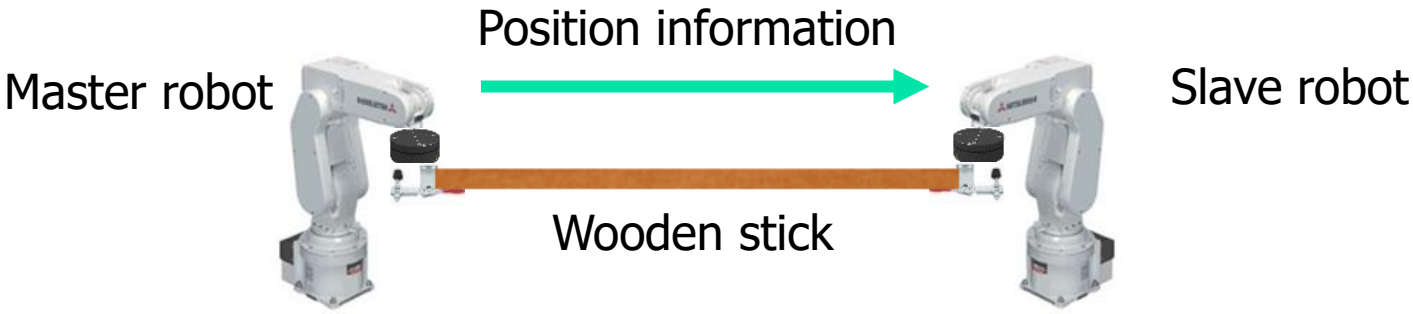
Remote robot system with force feedback



- A user can remotely control a robot having a force sensor by using a haptic interface device.
- It is possible for the user to perceive shapes, weights, and softness of remote objects hit/touched by a robot arm through the haptic interface device (i.e., force feedback).

Background (2/3)

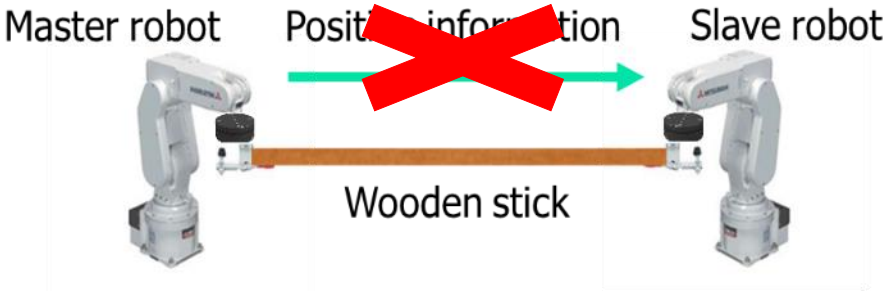
Cooperative work of carrying a wooden stick together is possible by using multiple remote robot systems.



When there is a master-slave relationship between robots, the master robot's position information is transmitted to the slave robot to follow.

Background (3/3)

- Network environments are not always good.
- Position information cannot be transmitted in poor network environments.



We can use the robot movement control using force information to perform cooperative work between systems without communication.

Previous Work

*1 Y. Hara *et al.,* Proc. NetGames, Nov. 2022.
*2 Y. Ishibashi *et al.,* Proc. IEEE ICCE-TW. July 2022.

- Cooperative work of carrying the wooden stick together between two remote robot systems with force feedback

- The adaptive Δ-causality control was applied to two remote robot systems that have a master-slave relationship, and its effect was examined. *1

- The robot position control using force information was proposed to enable cooperative work even when communication between robots is difficult.*2

Purpose of This Work

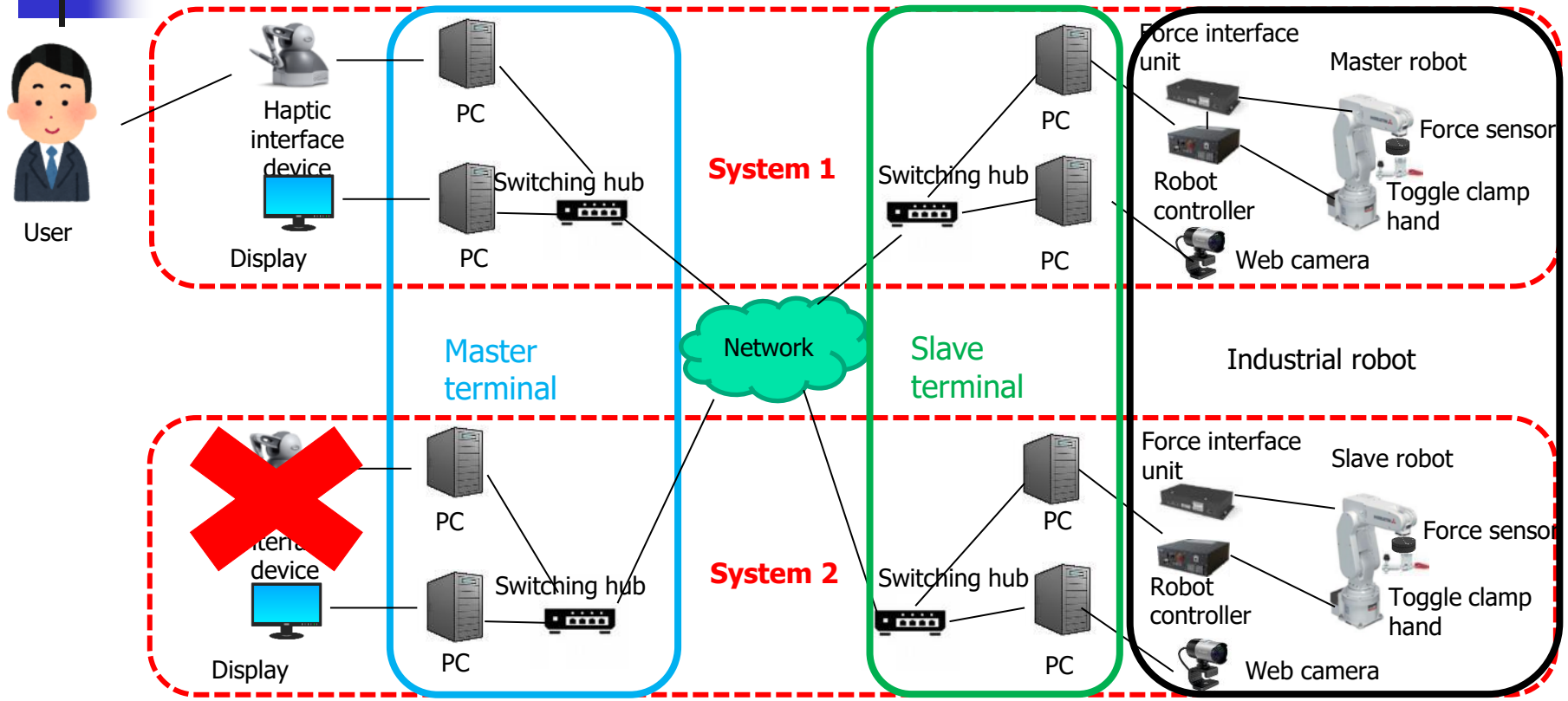
Problems of previous work

- If the communication quality changes over time, it is possible to switch the control using position information or force information according to the communication quality.
- However, such considerations have not been made to date.

Purpose of this work

We switch between the two types of control using position information or force information according to the communication quality, investigate the influence of changes in communication quality, and clarify the effect of switching control.

Remote Robot Systems with Force Feedback



- The master robot was moved using the haptic interface device while a user of the master robot watched video.
- The slave robot followed the movement of the master robot using the robot position control based on either position information or force information.

Robot Position Control Using Position Information

*1 Y. Hara *et al.,* Proc. NetGames, Nov. 2022.

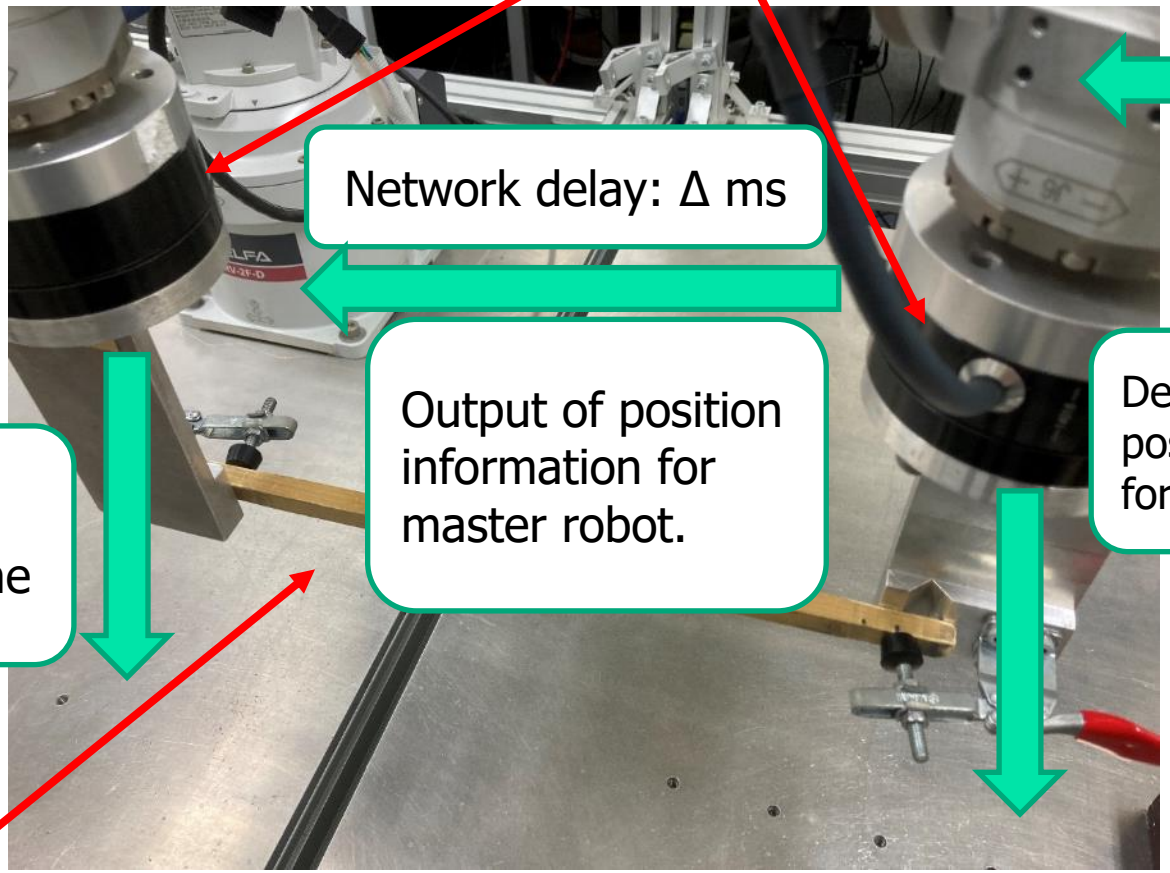
The adaptive Δ-causality control*1

Haptic interface device

Force sensor

Master robot

Slave robot



Output of position information.

Network delay: Δ ms

Output of position information for master robot.

Delay the output of position information for Δ ms.

The slave robot follow the movement of the master robot.

Move the master robot.

Wooden stick

Robot Position Control Using Force Information (1/2)

*2 Y. Ishibashi *et al.,* Proc. IEEE ICCE-TW. July 2022.

Control by motion equation *2

Haptic interface device

Force sensor

Master robot

Output of position information.

Slave robot

Detect applied force.

Difference in position and force is applied.

The slave robot is moved in the direction that reduces the force

Move the master robot.

Wooden stick

Robot Position Control Using Force Information (2/2)

*2 Y. Ishibashi *et al.,* Proc. IEEE ICCE-TW, July 2022.

*3 S. Ishikawa *et al.,* Proc. WSCE, Dec. 2019

Control by motion equation *2

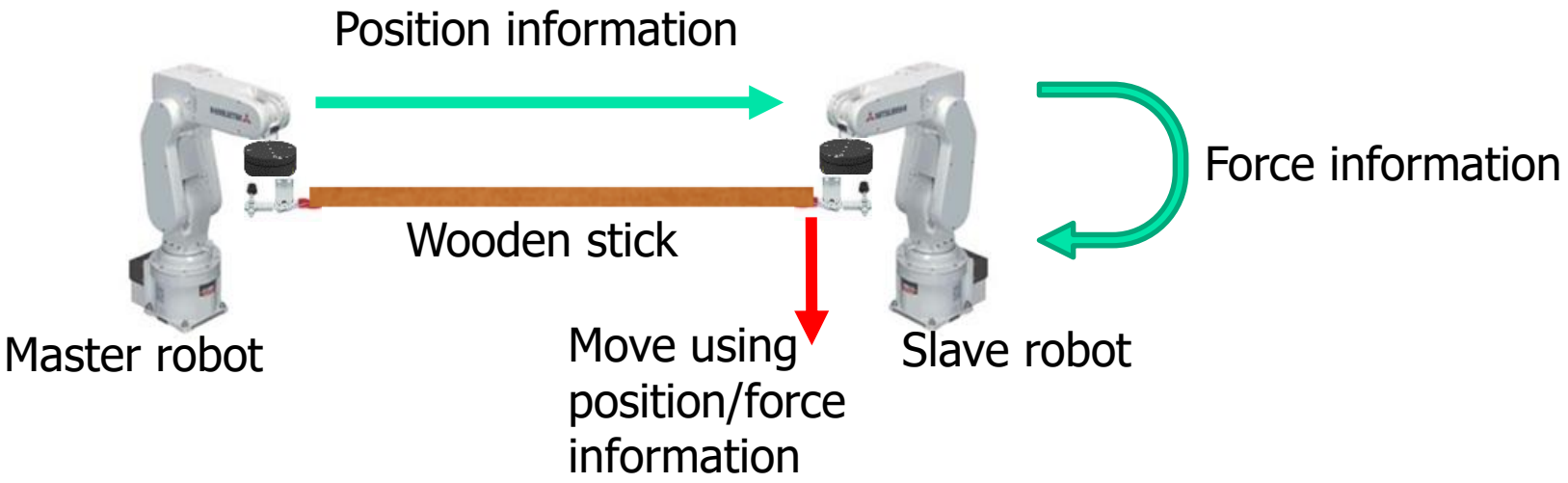
$$\boldsymbol{P}_t = \begin{cases} 0.9\boldsymbol{P}_{t-1} + 0.279\boldsymbol{F}_t \ (\text{if } |\boldsymbol{P}_{t-1}| \geq 0.1 \text{ mm}) \\ 0.279\boldsymbol{F}_t \ (\text{Otherwise}) \ ^{*3} \end{cases} \quad (1)$$

$\boldsymbol{P}_t$: Position adjustment vector

$\boldsymbol{F}_t$: Sensed force

Control by motion equation using motion equation and time and distance formulas is proposed to use force information efficiently.

Switching Control

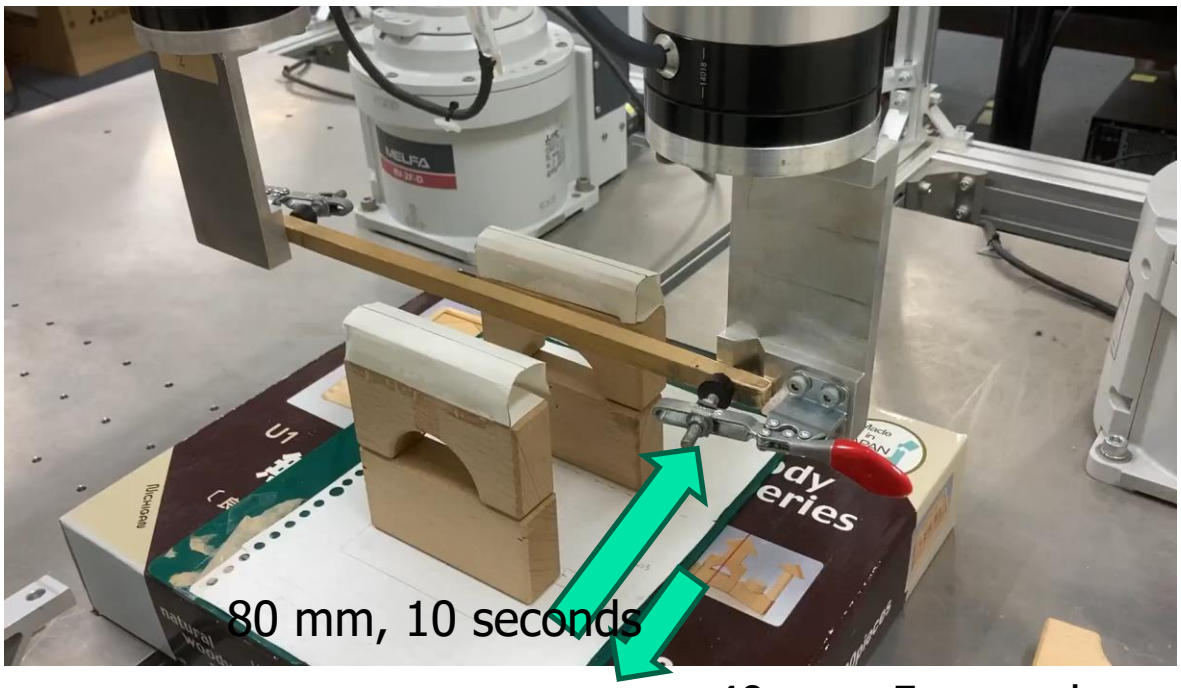


- The position information is received, the slave robot is moved using the position information.
- When the position information is not received, the slave robot is moved using the force information.

Experiment Method (1/3)

To investigate the effect of temporal changes in communication quality during the task, we conducted two experiments.

The position information is received, the slave robot is moved using the information. When it is not received, the robot is moved using force information.



Experiment Method (2/3)

Experiment 1

- We interrupted communication for 2 seconds just before the turn, during the turn, and just after the turn.
- We conducted experiments with and without switching control, and measured the force applied to the wooden stick.

Experiment Method (3/3)

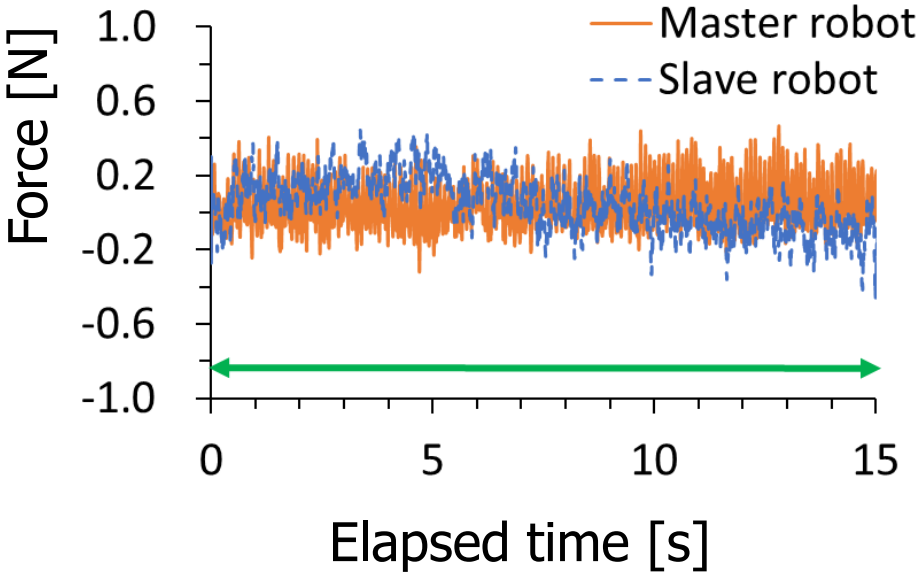
Experiment 2

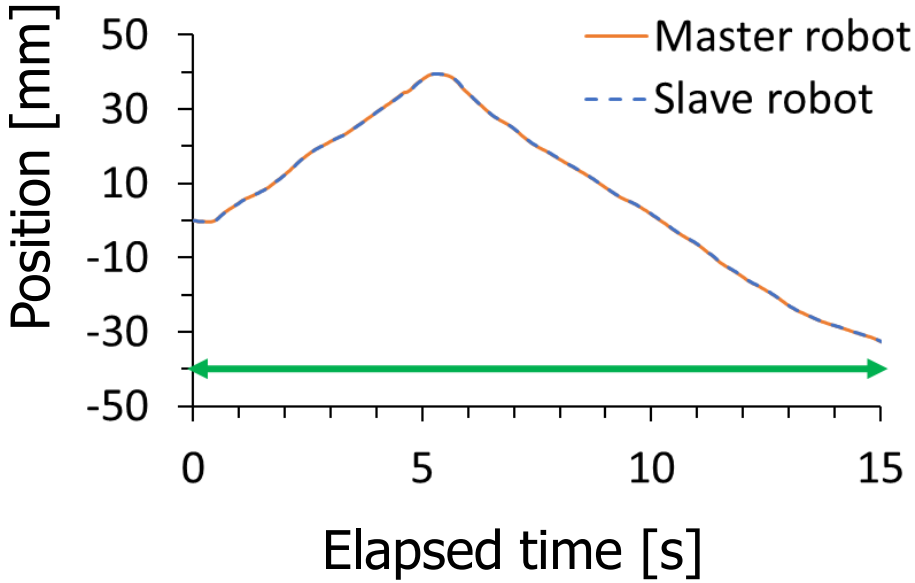
- We uniformly dropped position information for 10 seconds after the start of the experiment to simulate degraded communication quality.
- Loss rate: 0%, 10%, 25%, 50%, ･･･, 100%
- We conducted experiments with and without switching control, and measured the force applied to the wooden stick.

Experimental Results (1/6)

Using position information
Using force information

When using the position information
(i.e., when communication is not interrupted).



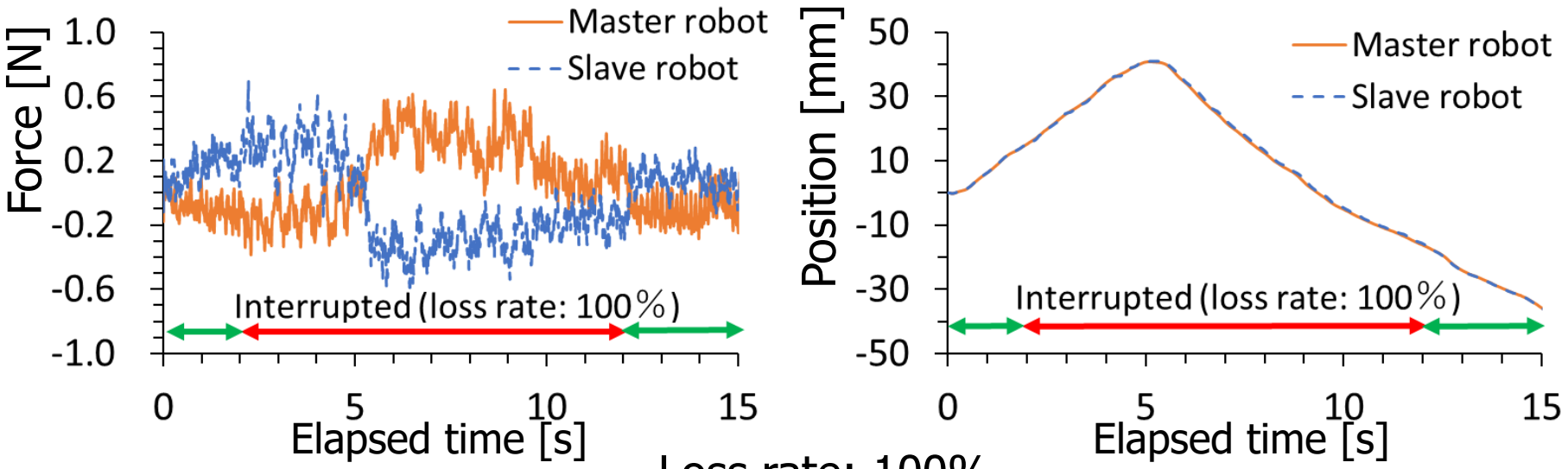


Loss rate: 0%

- We see that the force is small, and the positional deviation between the two robots is also small.

Experimental Results (2/6)

Using position information
Using force information



Loss rate: 100%
With switching control

- We also conducted experiments without switching the control when communication was interrupted, but we omitted the results, resulting in sudden and large position changes from a distant position when communication was restored; because the limit of the allowable movement speed was exceeded, we stopped the systems for safety.

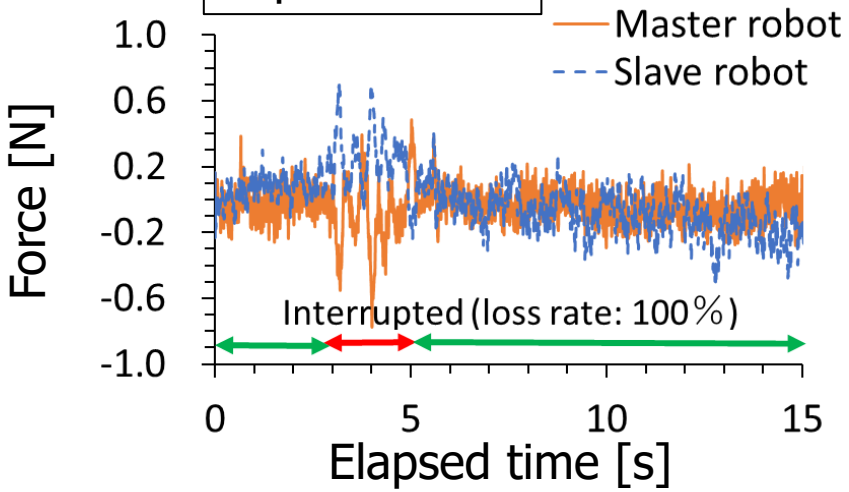
- We observe that the force when using force information is suppressed, but relatively large force is applied compared to the case of position information.

Experimental Results (3/6)

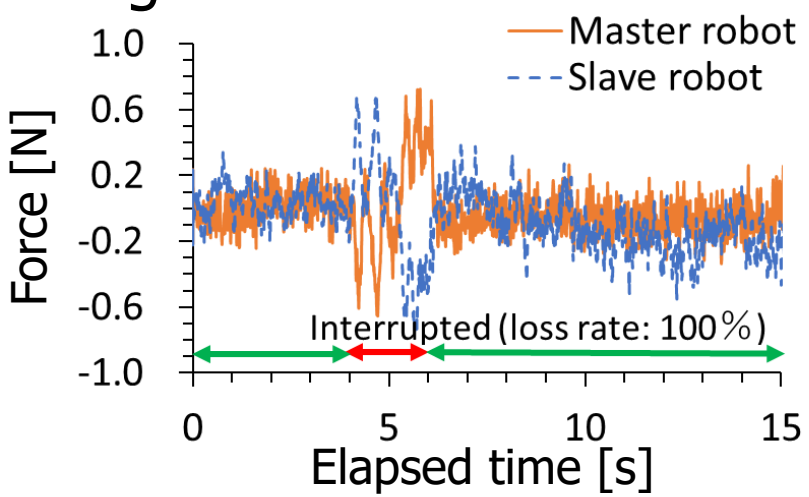
Using position information
Using force information

Experiment 1

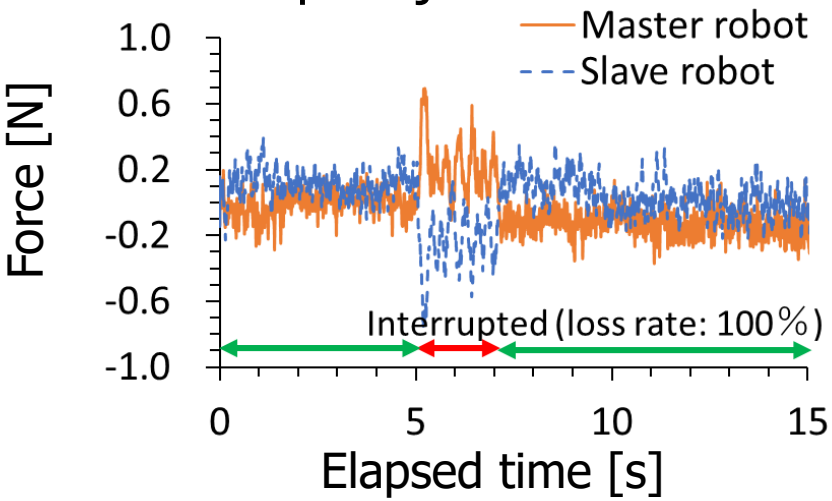
With switching control



Interrupted just before the turn.



Interrupted during the turn.



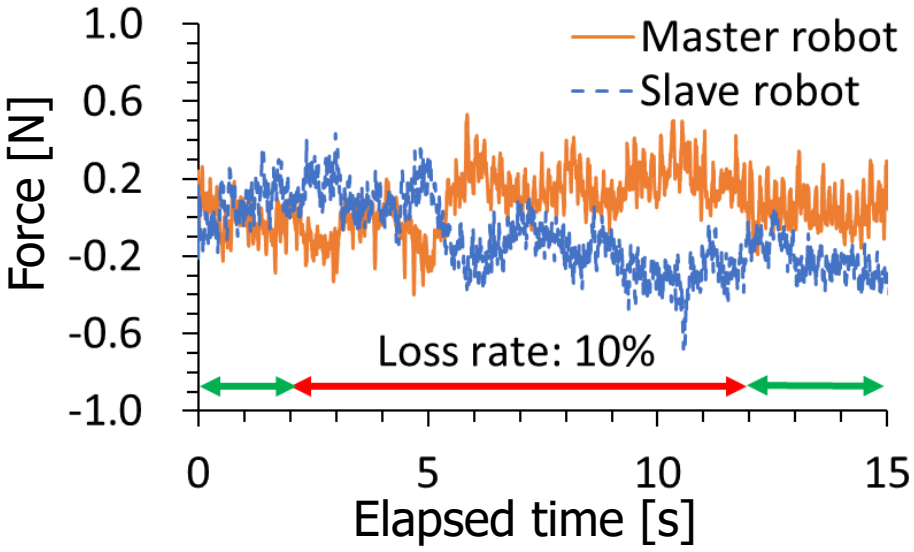
Interrupted just after turn.

- The force is almost the same in the case where the control is switched when communication is interrupted.
- This indicates that the switching control is effective.

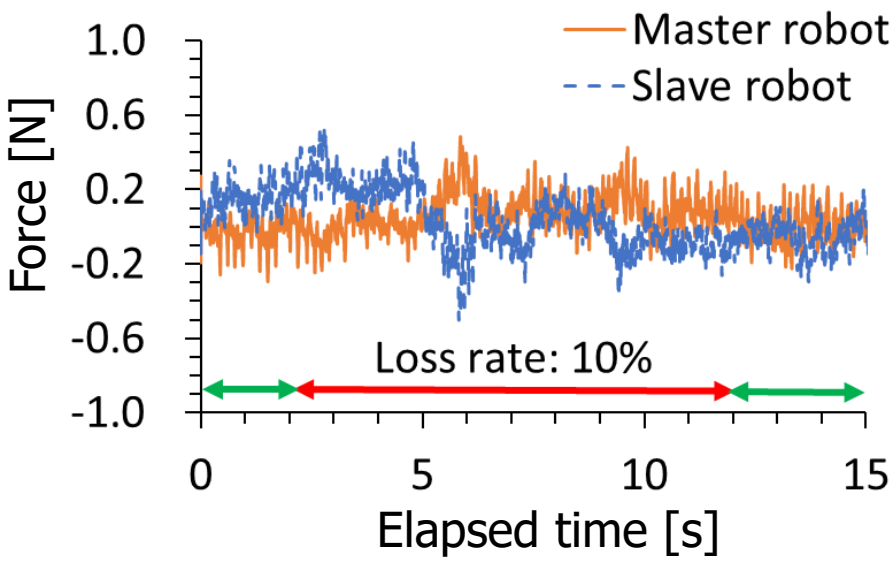
Experimental Results (4/6)

Using position information
Using force information

Experiment 2



Without switching control



With switching control

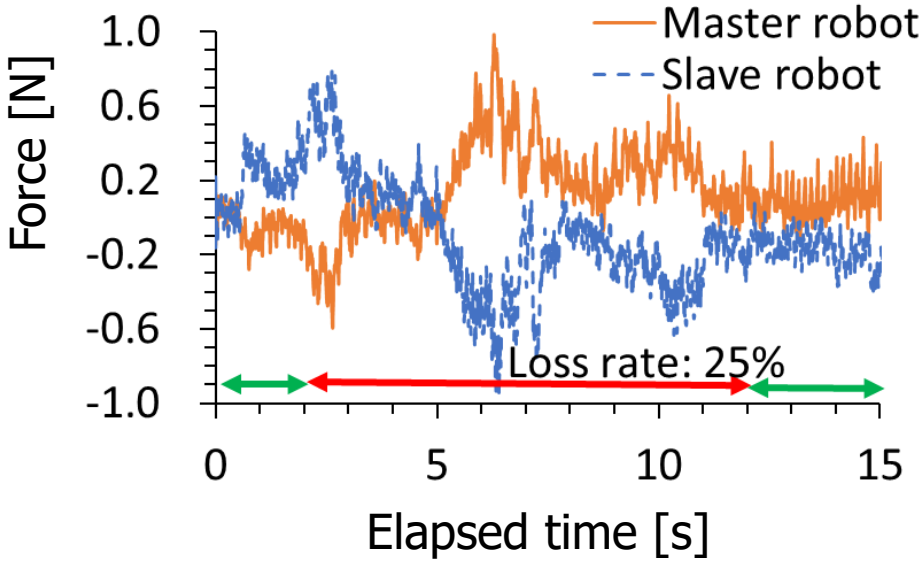
Loss rate: 10%

- When the loss rate is 10% and the control is not switched, the force tends to be slightly larger compared to when the control is switched.

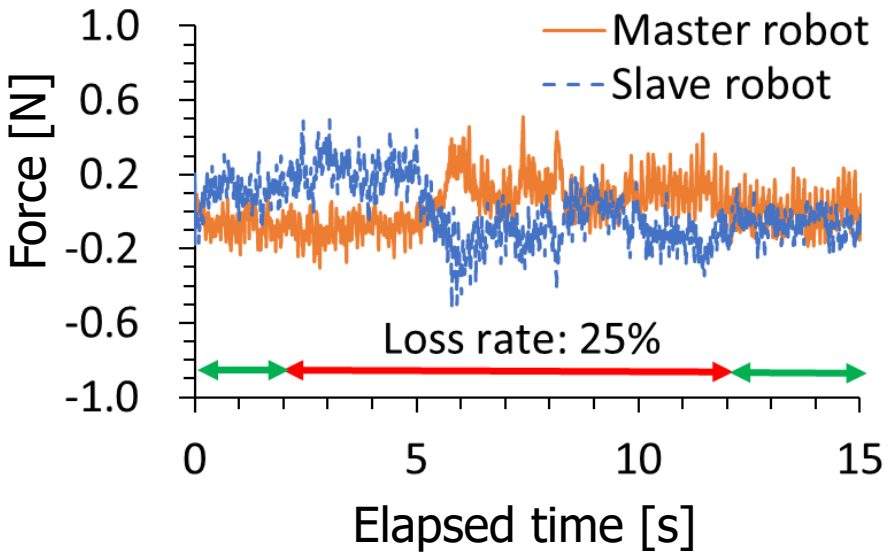
Experimental Results (5/6)

Using position information
Using force information

Experiment 2



Without switching control



With switching control

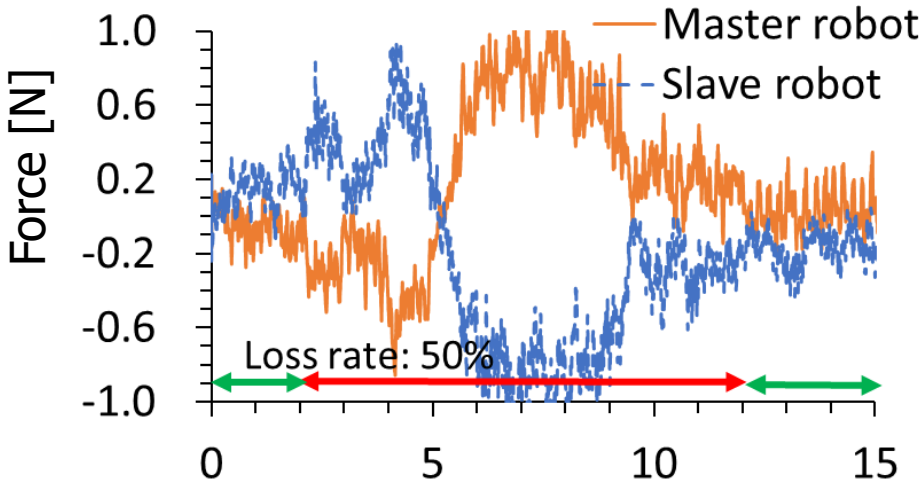
Loss rate: 25%

- When the loss rate is 25% and the control is not switched, the force is larger than that when the loss rate is 10%.

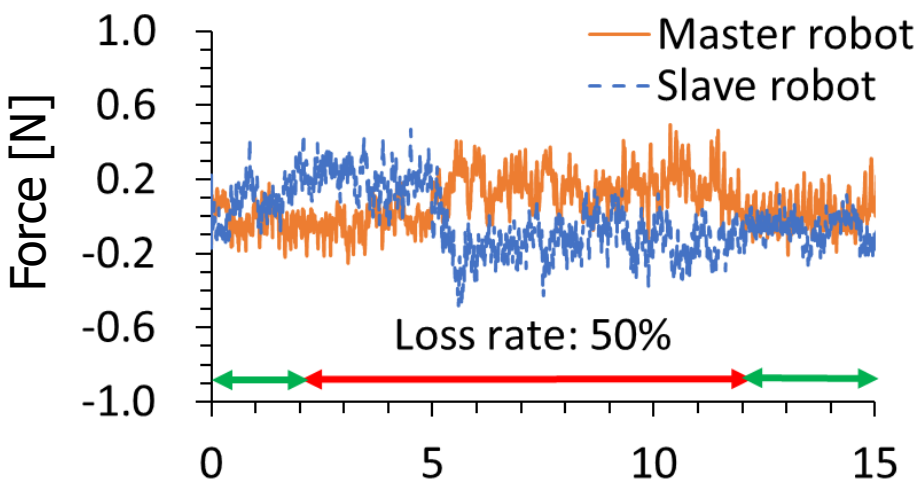
Experimental Results (6/6)

Using position information
Using force information

Experiment 2



Without switching control



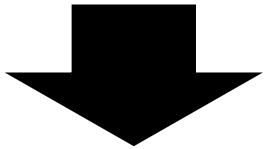
With switching control

Loss rate: 50%

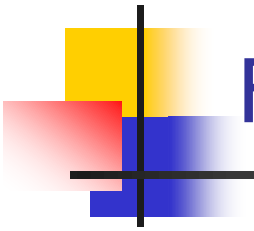
- When switching control, the force remains almost equal regardless of whether the loss rate is 10%, 25%, or 50%.

Conclusion

We conducted experiments using remote master-slave robot systems with force feedback to perform work of carrying an object.
We switched from control using position information to control using force information when the communication quality deteriorated.



- The switch in control is effective.
- As the loss rate of position information increases, the switch in control becomes more effective.



Future Work

- Plan to investigate influences of network delays
- Study how to improve the control using force information so that the control can suppress the force to almost the same extent as the control using position information