Effect of Object Movement Control for Remote Robot Systems with Force Feedback

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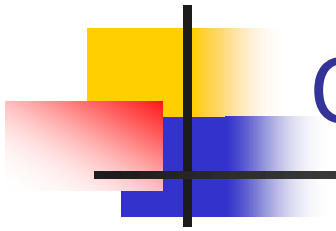
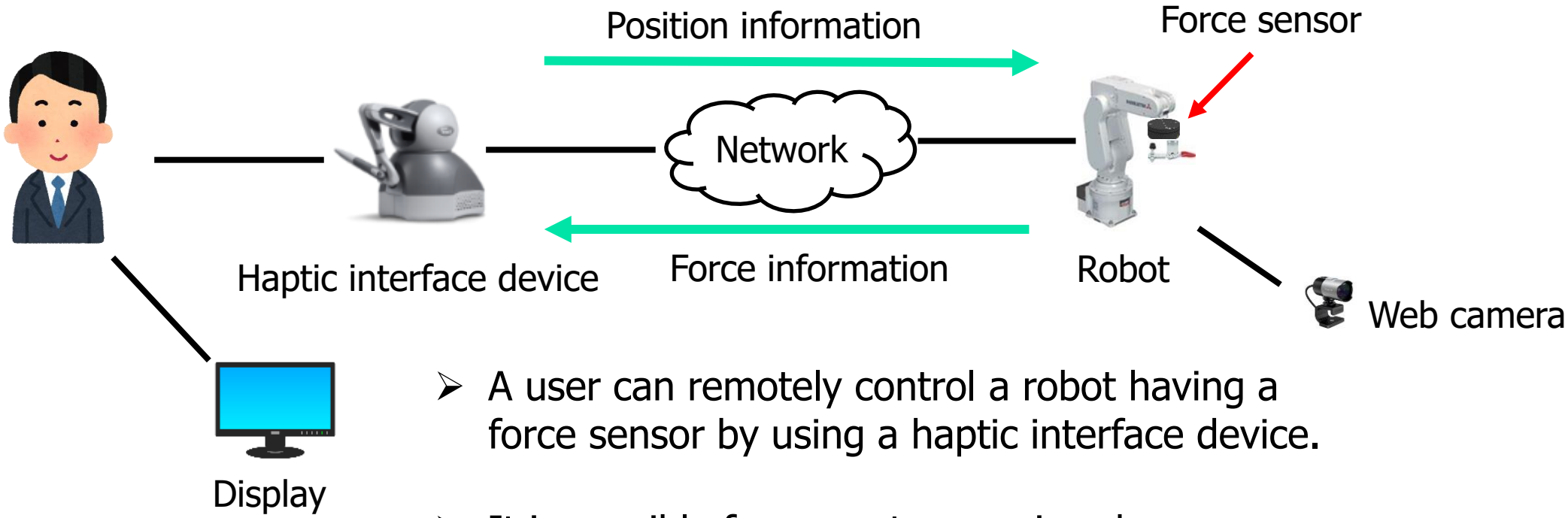


Outline

- Background
- Previous Work
- Purpose of This Work
- Remote Robot Systems with Force Feedback
- Object Movement Control
- Experiment Method
- Experimental Results
- Conclusion
- Future Work

Background (1/3)

Remote robot systems with force feedback

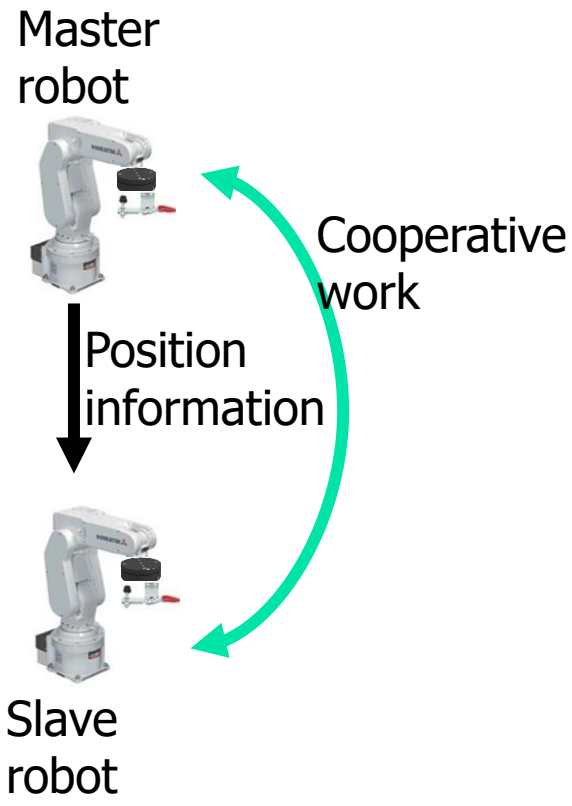


- A user can remotely control a robot having a force sensor by using a haptic interface device.
- It is possible for users to perceive shapes, weights, and softness of remote objects hit/touched by robot arm through haptic interface device (i.e., force feedback).

Background (2/3)

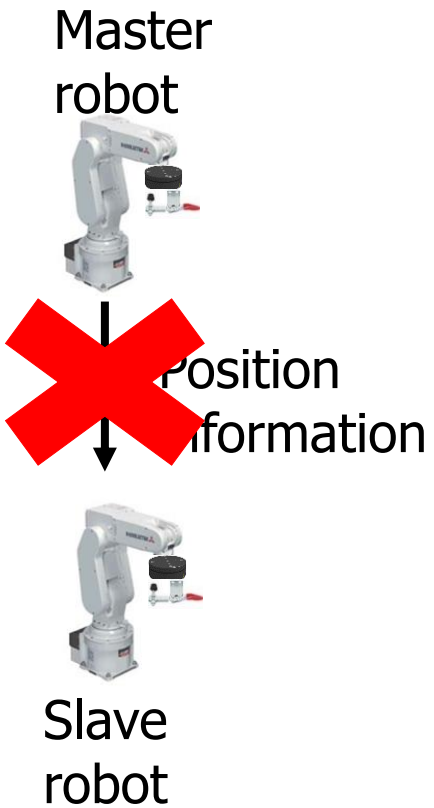
Cooperative work is possible by using multiple remote robot systems.

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



Background (3/3)

Network environments are not always good.
Poor network environments may cause various problems.



- Cooperative work between the systems without communication
- Robot movement control using force information

Previous Work

*1 Y. Ishibashi *et al.,* Proc. IEEE ICCE-TW., July 2022.
*2 H. Nakagawa *et al.,* Proc. IEICE, Jan. 2023.

- Cooperative work of carrying an object together between two remote robot systems with force feedback.
- One robot is set to move automatically at average velocity and the other follows.

- Propose and compare with robot movement control using force sensor in the front-back direction including human operation. As a result, experimental results demonstrated that human operation is the best. And control by motion equation is closest human operation.*1
- Propose and evaluate the effect control in the up-down direction to respond more quickly to sudden position change.*2

Purpose of This Work

Problems of previous work

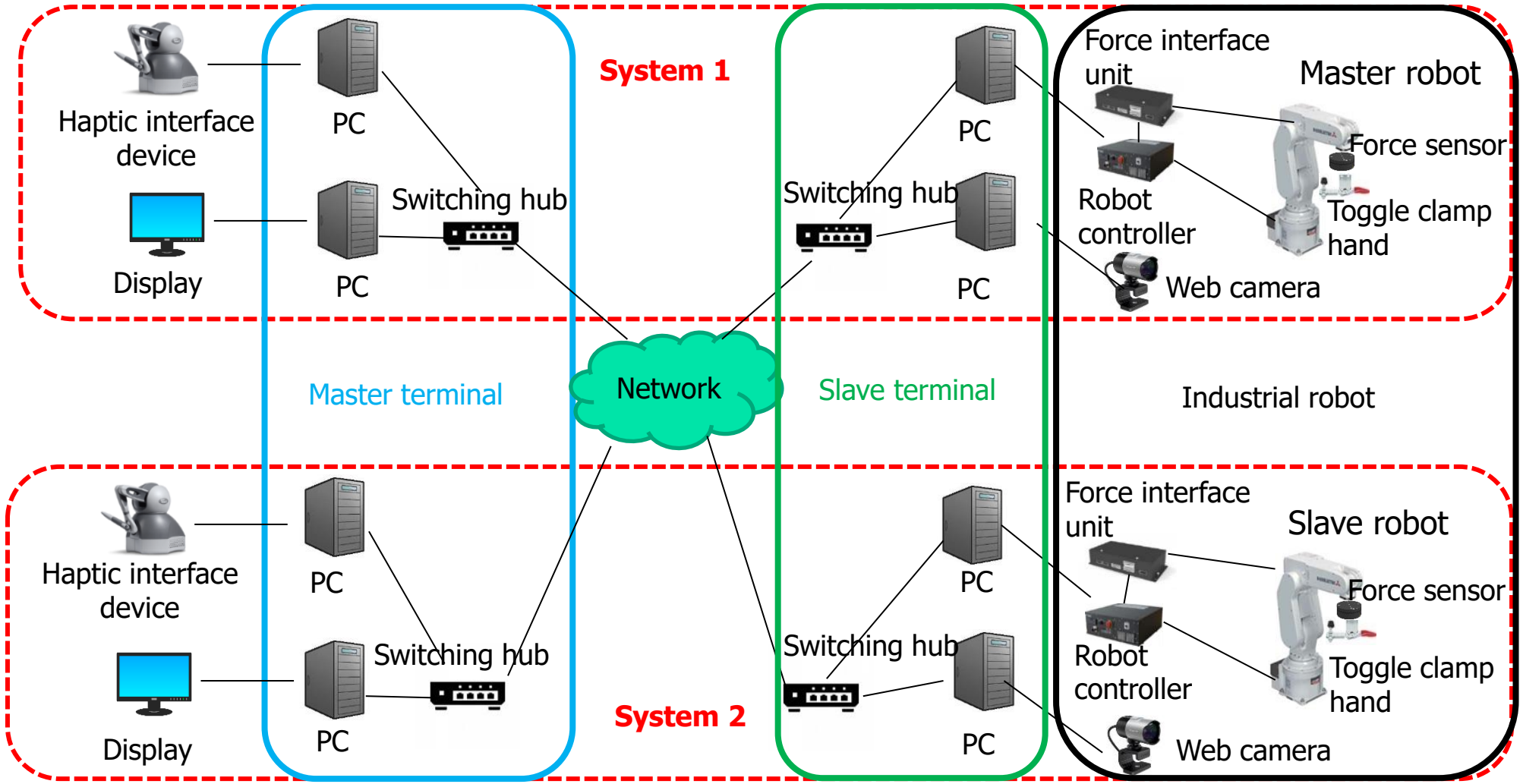
Because of the control in the left-right direction has not been carried out, large force is applied to the left-right direction.

Purpose of this work

Previous work demonstrated that control by motion equation is the best in the front-back direction.

We compare four types of object movement control in the left-right direction including human work instead of one robot.

Remote Robot Systems with Force Feedback



Object Movement Control in the front-back

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

Control by motion equation*1

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

$\boldsymbol{P}_t$: Position adjustment vector
$\boldsymbol{F}_t$: Sensed force

In all types of experiments, the front-back direction uses control by motion equation.

Object Movement Control in the left-right (1/4)

*3 S. Ishikawa *et al.,* Proc. IJCNS. pp. 1-13, Mar 2021.

Position control*3

$$\boldsymbol{P}_t = a\,\boldsymbol{F}_t \quad (2)$$

$$a = 0.117 \quad (3)$$

$\boldsymbol{P}_t$: Position adjustment vector
$\boldsymbol{F}_t$: force applied to wooden stick
a : Coefficient (depending on length of wooden stick)

Position control finely adjusts the position of the robot arm in the direction where the force is reduced.

Object Movement Control in the left-right (2/4)

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

Control by motion equation[*1]

$$\boldsymbol{P}_t = \begin{cases} \alpha\, \boldsymbol{P}_{t-1} + 0.112\, \boldsymbol{F}_t \ (\text{if } |\boldsymbol{P}_{t-1}| \geq 0.1 \text{ mm}) \\ 0.112\, \boldsymbol{F}_t \ (\text{otherwise}) \end{cases} \quad (4)$$

$$\alpha = \begin{cases} 0.9 \ (v \leq 24 \text{ mm/s}) \\ 0.4 \ (v > 24 \text{ mm/s}) \end{cases} \quad (5)$$

$\boldsymbol{P}_t$: Position adjustment vector
$\boldsymbol{F}_t$: Sensed force
α : Coefficient (depending on movement velocity of the robot arm)
v : Movement velocity of the robot arm (mm/s)

Object Movement Control in the left-right (3/4)

No control

- Neither the control by motion equation nor the position control is exerted in the left-right direction.

Object Movement Control in the left-right (4/4)

Human operation

- A human conducts the cooperative work instead of one robot.
- The human grasps a wooden stick with the reacher instead of the robot while looking at the movement of the other robot directly.

Experiment Method (1/4)

- Carrying a wooden stick is moved 40 mm forward and 80 mm backward.

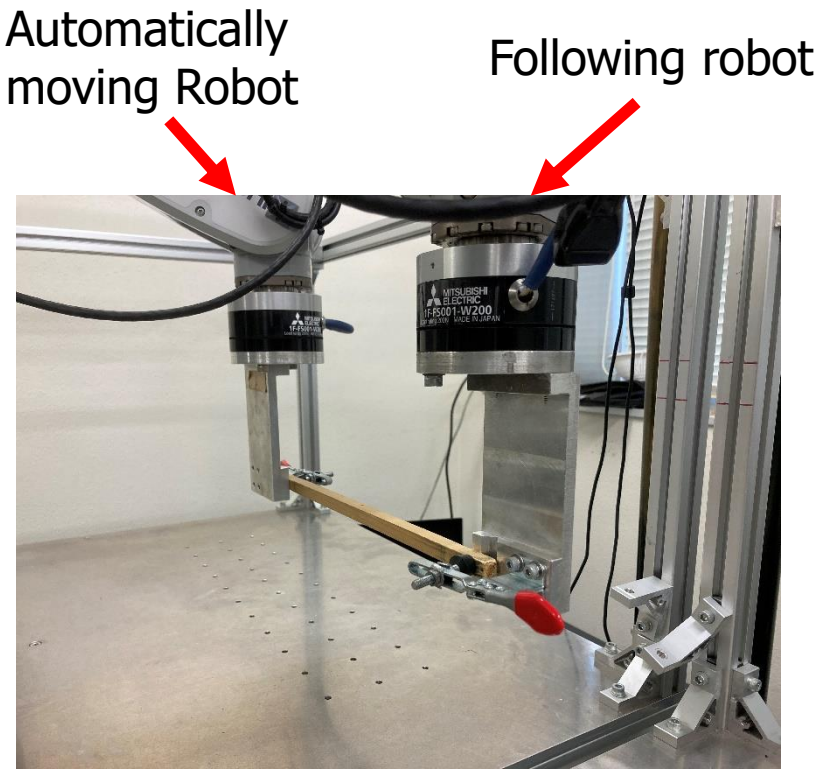
- We deal with two cases.
  - In one case, two robots work together.
  - In the other case, a human works by using a reacher instead of one robot.

- One robot is moved automatically at average velocity that is set to 8 mm/s, 16 mm/s, 24 mm/s, and 32 mm/s.

Experiment Method (2/4)

- **No control**
- **Position control**
- **Control by motion equation**

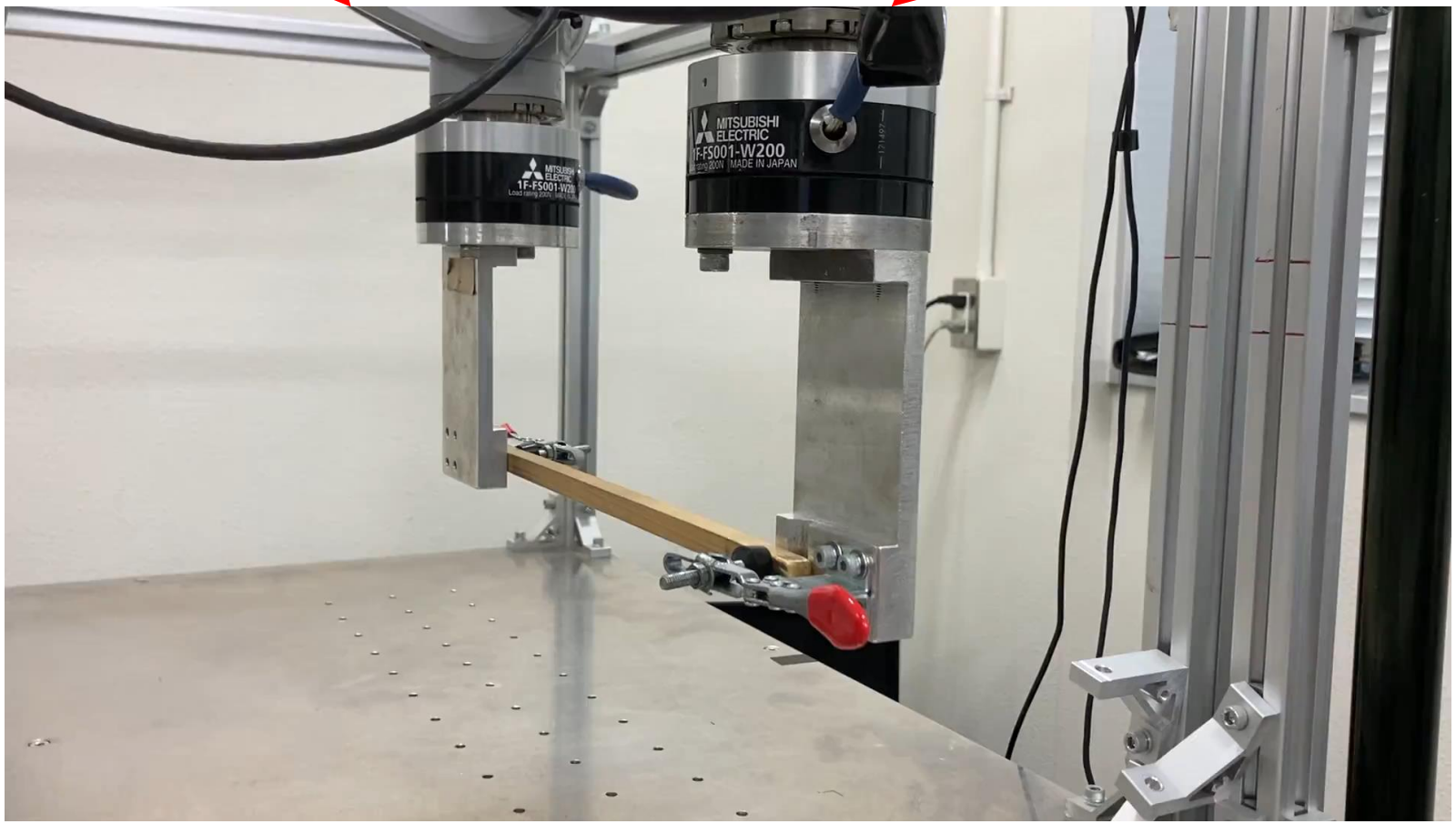
- Two robot arms grasp the wooden stick.
- One robot is set to move automatically.
- The other follows it by movement control.



Experiment Method (2/4)

Automatically moving Robot

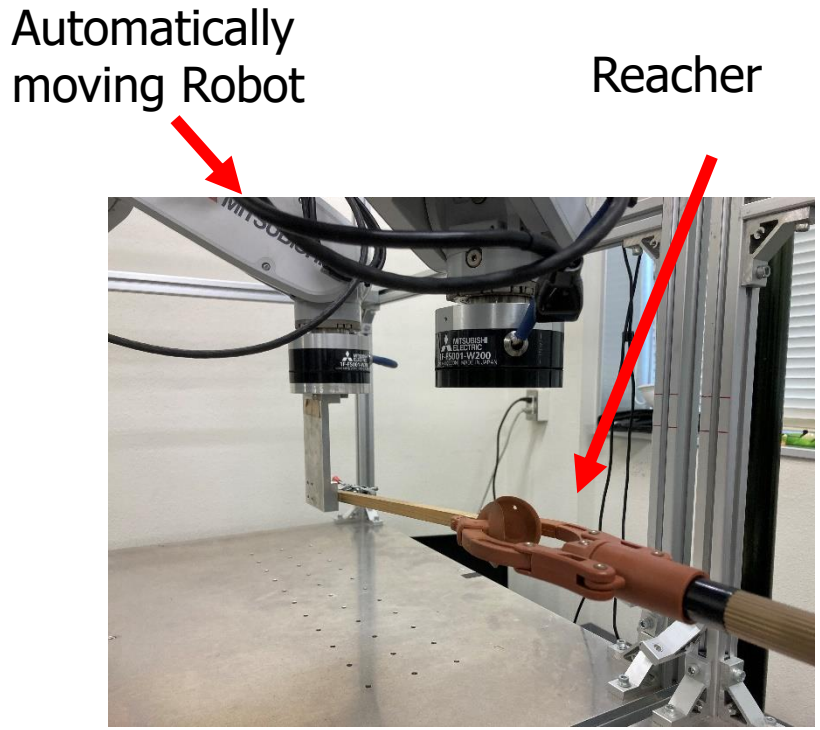
Following robot



Experiment Method (3/4)

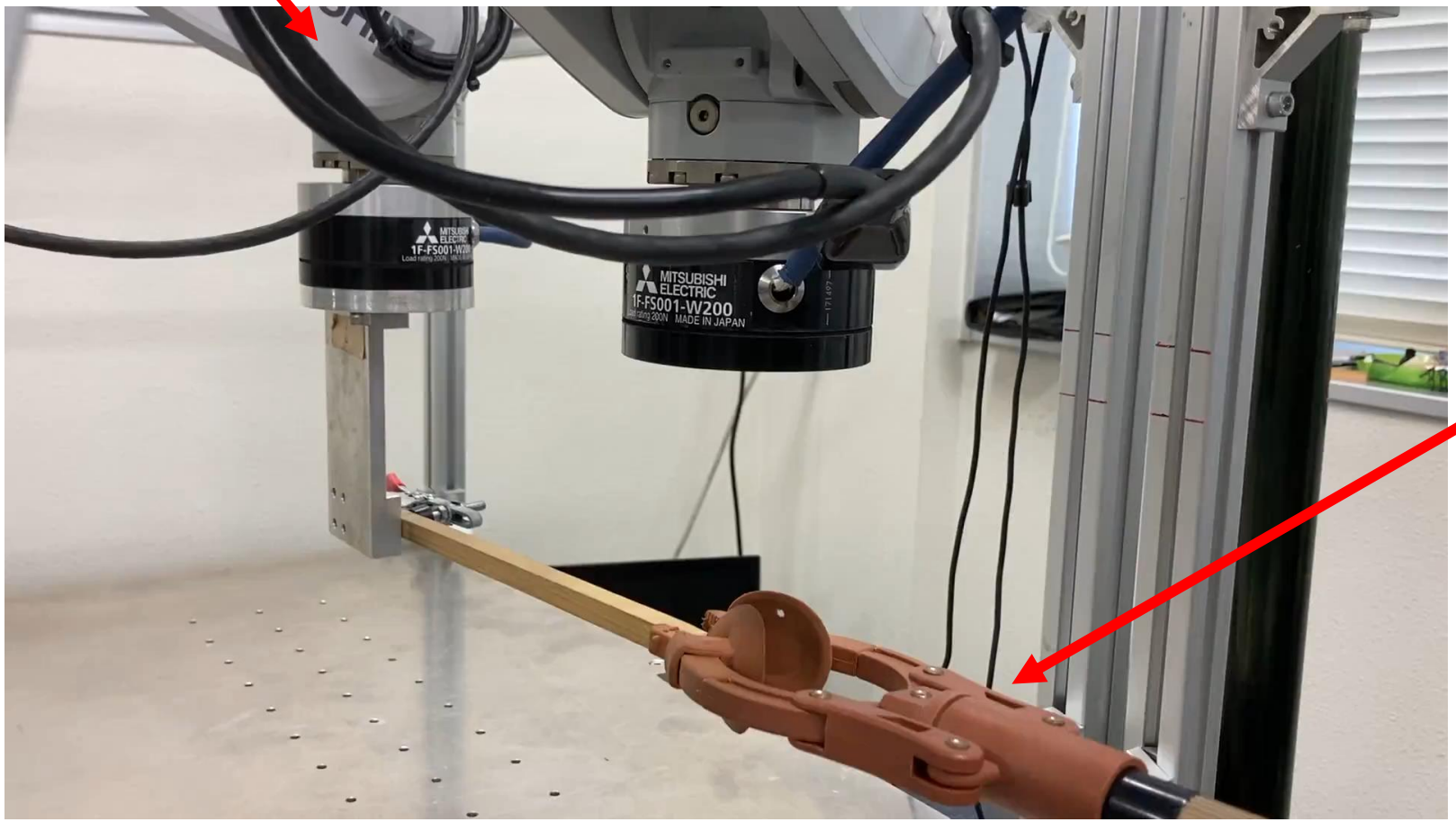
Human operation

- Human grasps a wooden stick with a reacher instead of the robot while looking at the movement of the other robot directly.



Experiment Method (3/4)

Automatically
moving Robot



Reacher

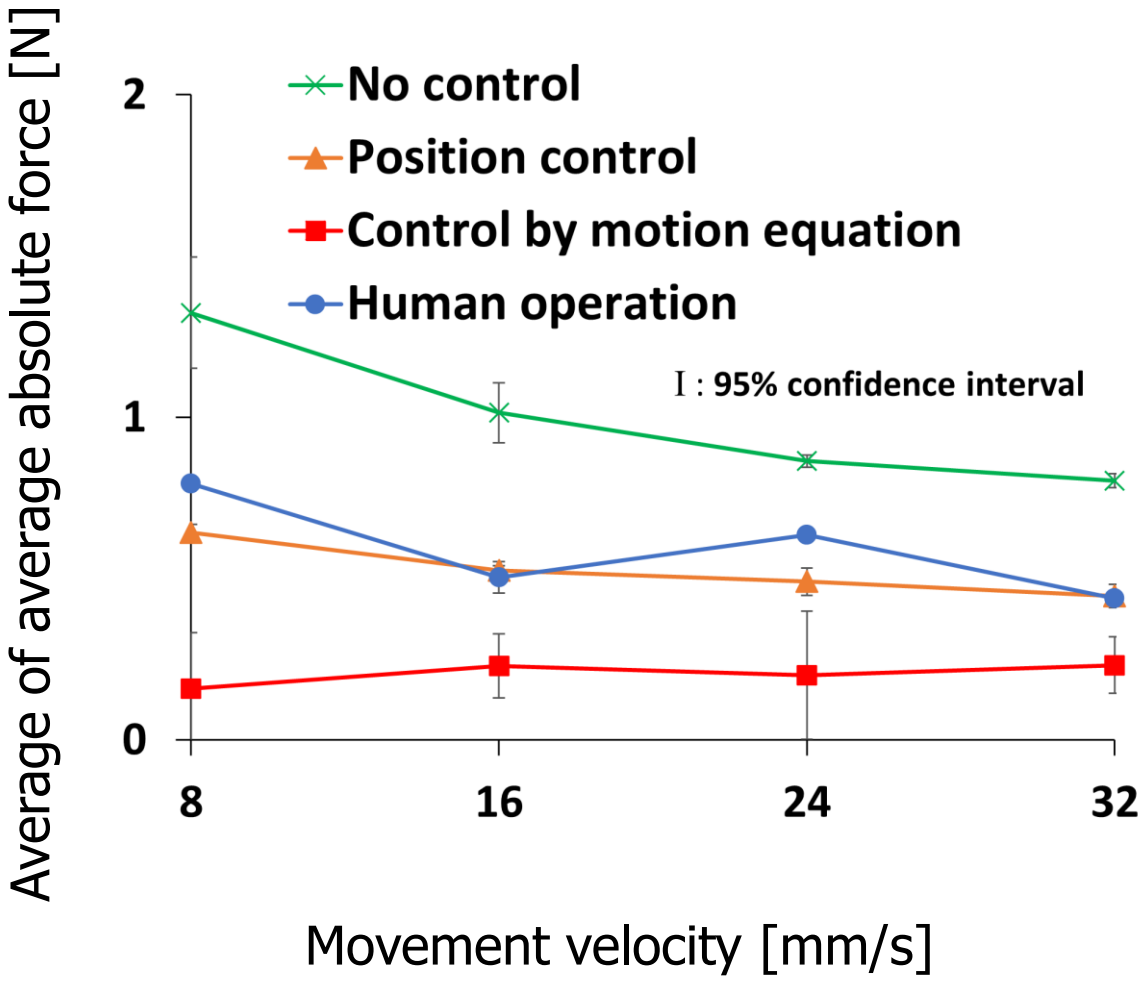
Experiment Method (4/4)

Comparison of four types of robot movement control

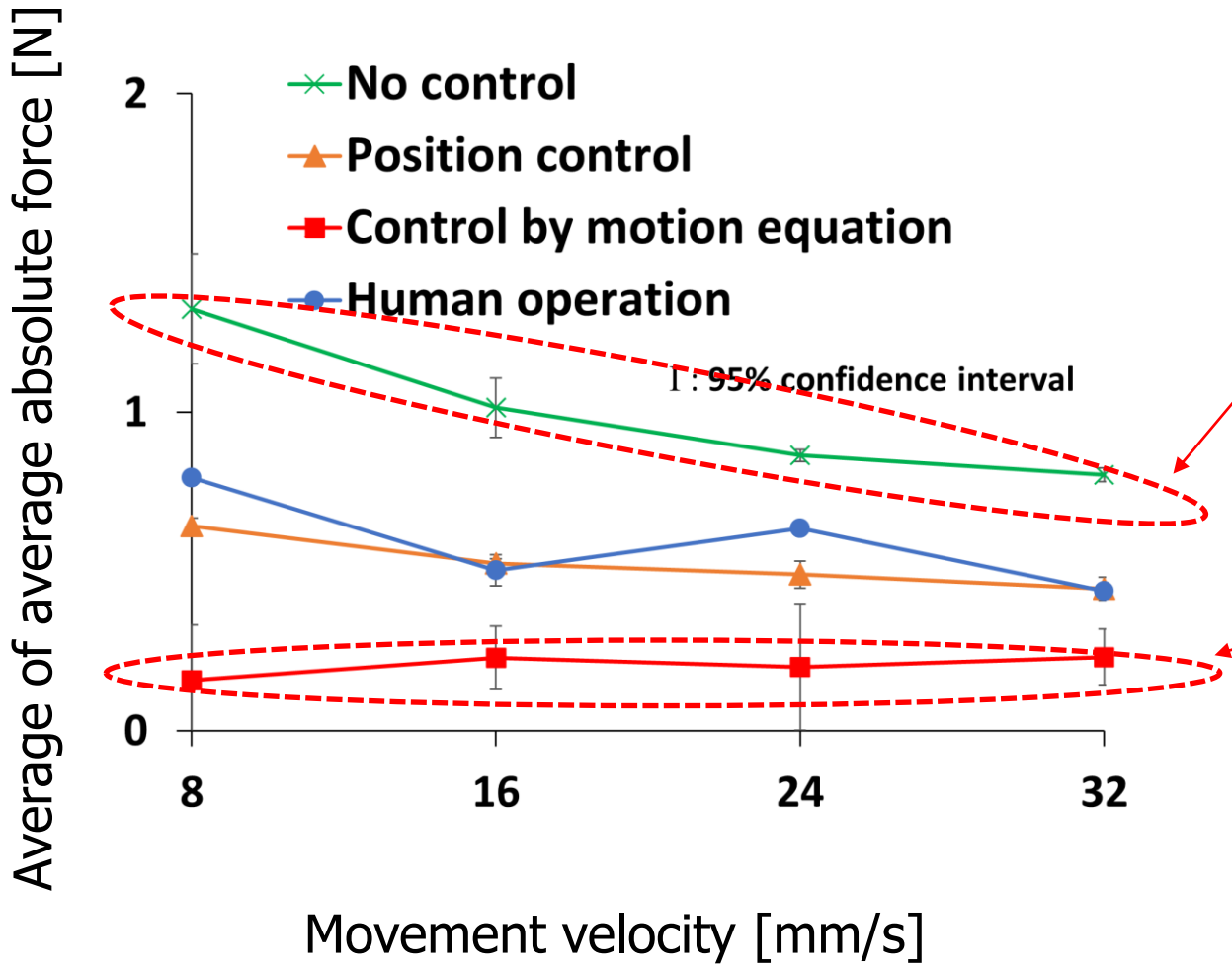
- ✓ No control
- ✓ Position control
- ✓ Control by motion equation
- ✓ Human operation

- Perform each experiment ten times and find the average of the force and the average of the maximum.

Experimental Results (1/2)



Experimental Results (1/2)



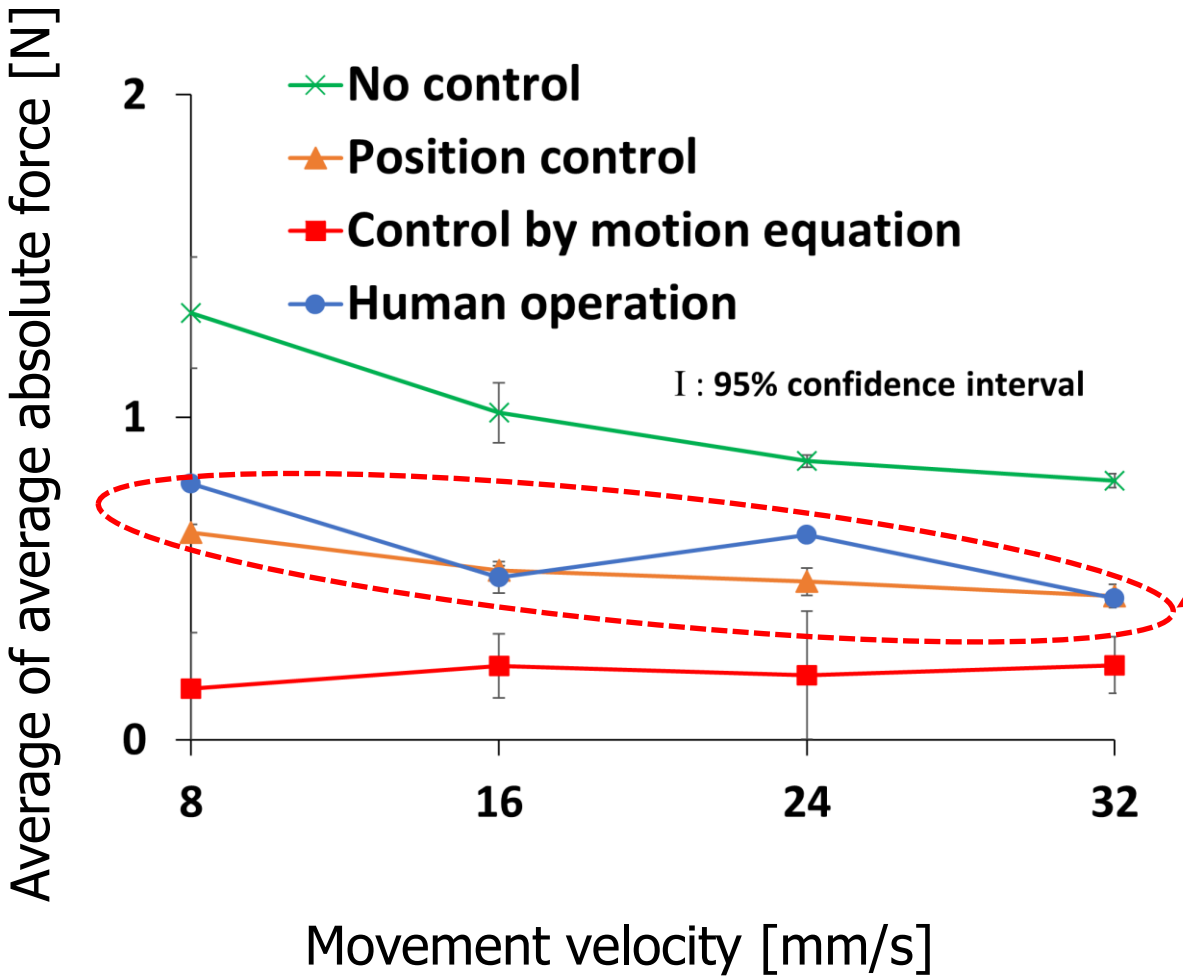
No control

The average is the largest.

Control by motion equation

The average is the smallest.

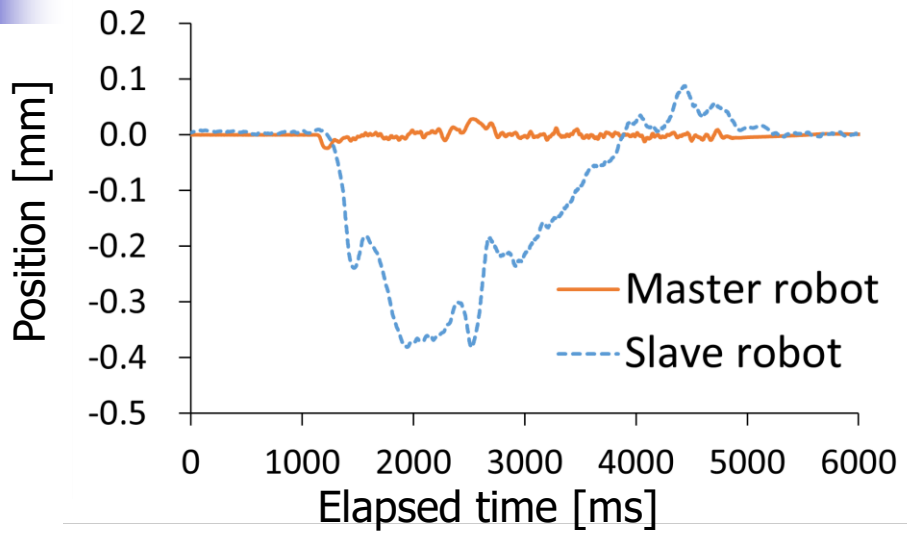
Experimental Results (1/2)

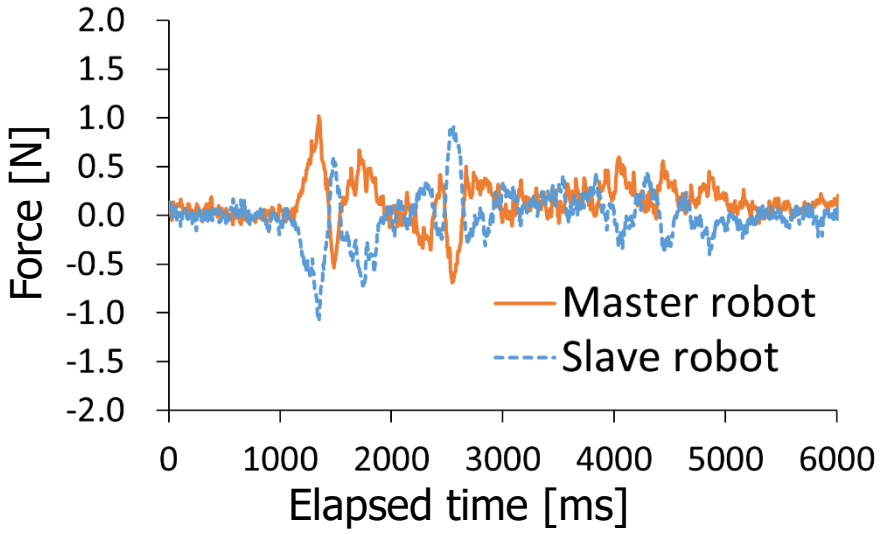


Position control and human operation

The average are less than or almost equal.

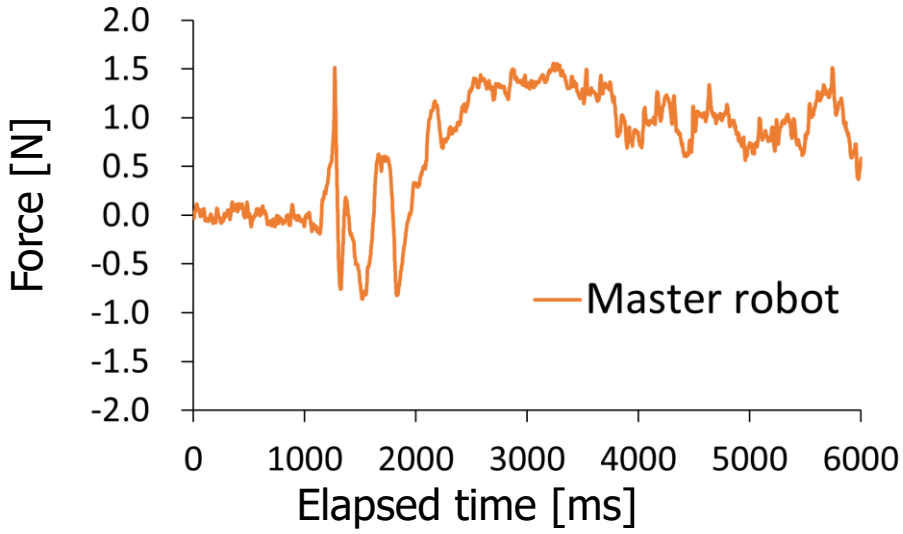
Experimental Results (2/2)





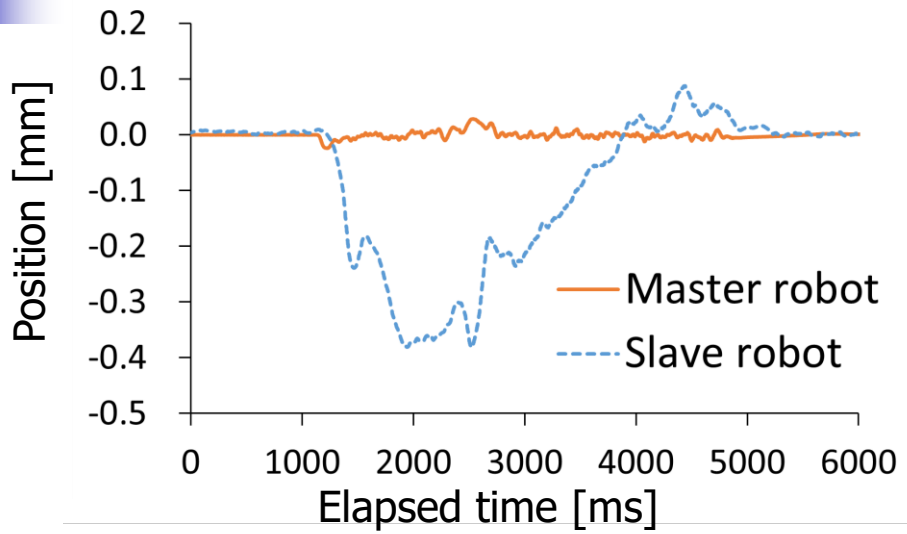
Control by motion equation

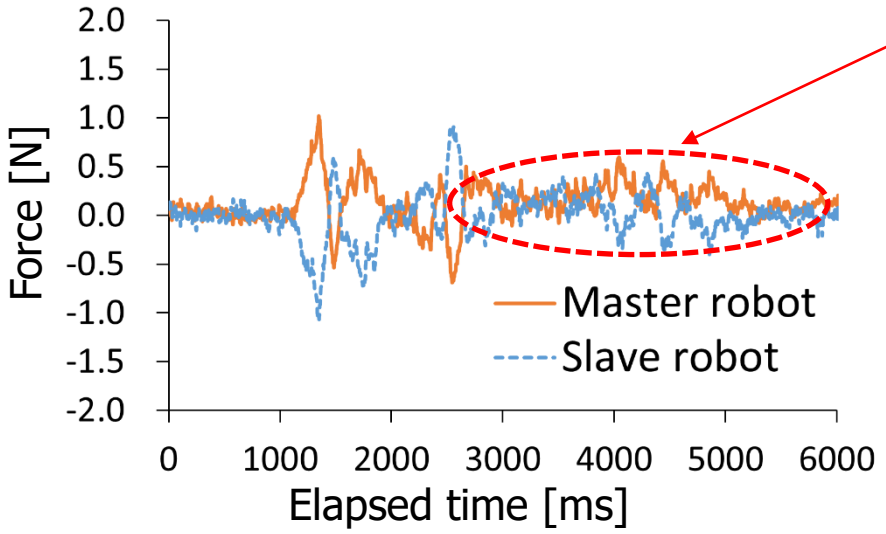
Since the position of human operation was almost the same as that of Master robot under the control by motion equation, we omitted the results.



Human operation

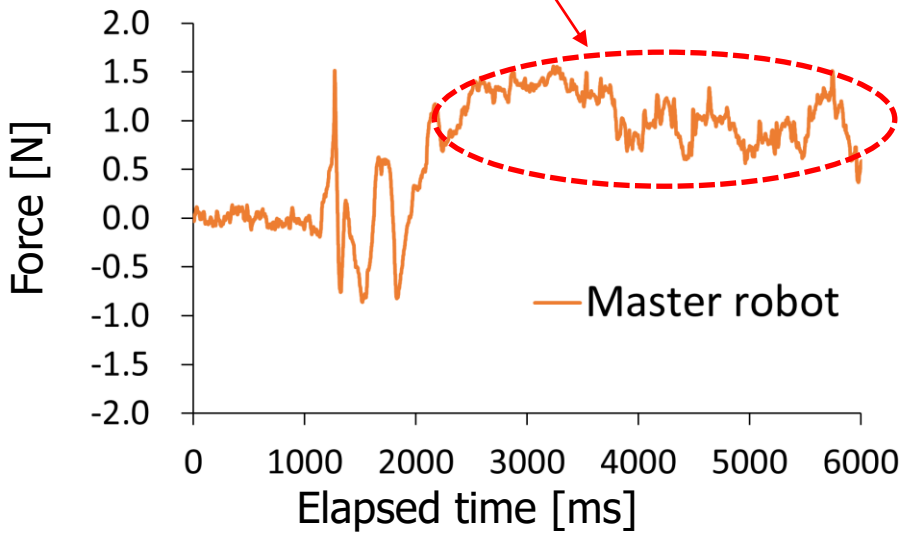
Experimental Results (2/2)





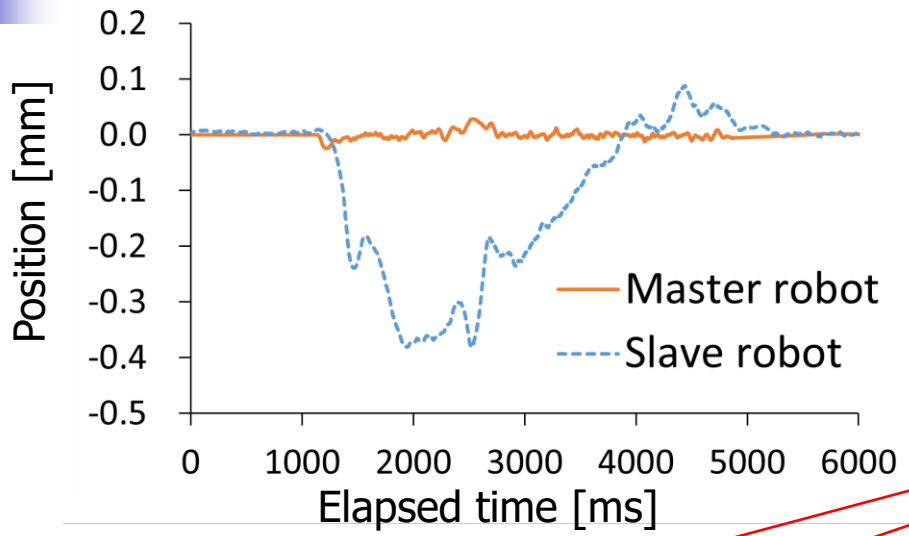
Control by motion equation

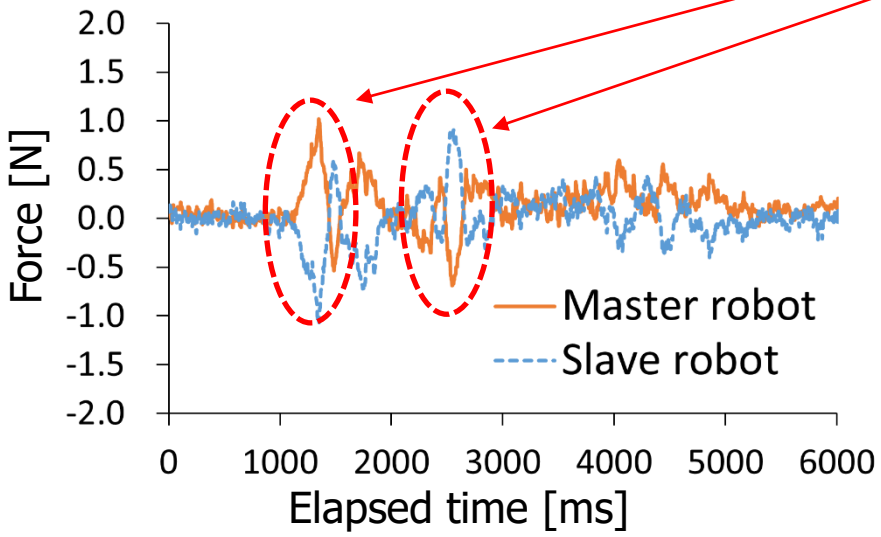
The force of control by motion equations is smaller than the force of human operation, especially after 2500ms.



Human operation

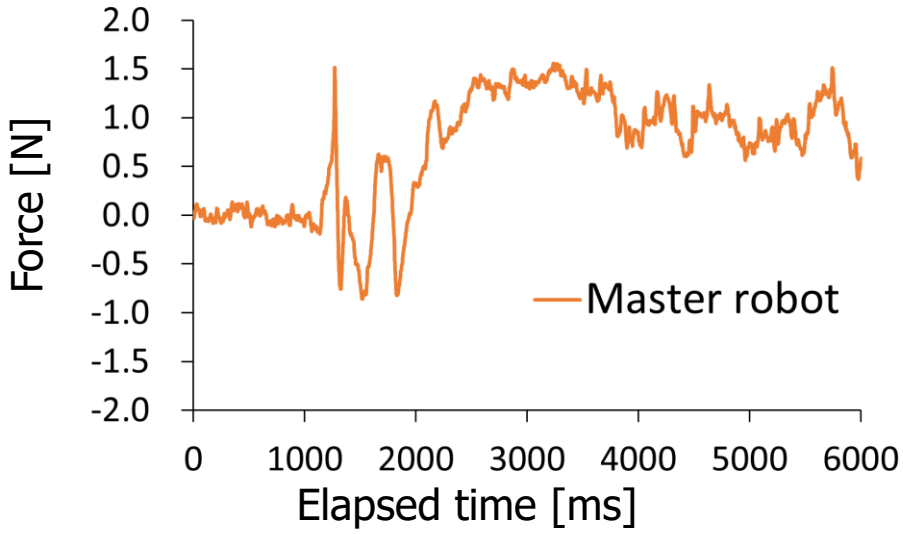
Experimental Results (2/2)





Control by motion equation

In the control by motion equation, the force is relatively high at the start to move and change the direction of movement.



Human operation

Conclusion (1/2)

Comparison of four types of object movement control including human operation in cooperative work of carrying an object between two remote robot systems with force feedback by experiment.

- The average control by motion equation is the smallest.
- The average of no control is the largest.
- The averages of position control and human operation are less than or almost equal.

Conclusion (2/2)

- Control by motion equation has smaller force than human operation.
- In the control by motion equation, the force is relatively high at the start to move and change the direction of movement.

Future Work

- Plan to improve the control by motion equation in various situations.
- Reduce the force at the beginning of the movement and at the changing of the movement direction.