# Comparison of Cooperative Work between Humans and Robots in Remote Robot Systems with Force Feedback

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# Background (1/2)

- Remote robot systems with force feedback have been attracting attention

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

- Various types of collaborative work are possible by using multiple systems

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 QoS (Quality of Service )**

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

**QoE (Quality of Experience) degradation**

**Instability phenomena**

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

# Previous Work

*1 L. Li *et al.*, ITE 70th Anniversary Convention, Dec. 2020.

**The effects of the stabilization control and QoS control on cooperative work (carrying a wooden stick together) between two remote robot systems with force feedback were investigated.**[*1]

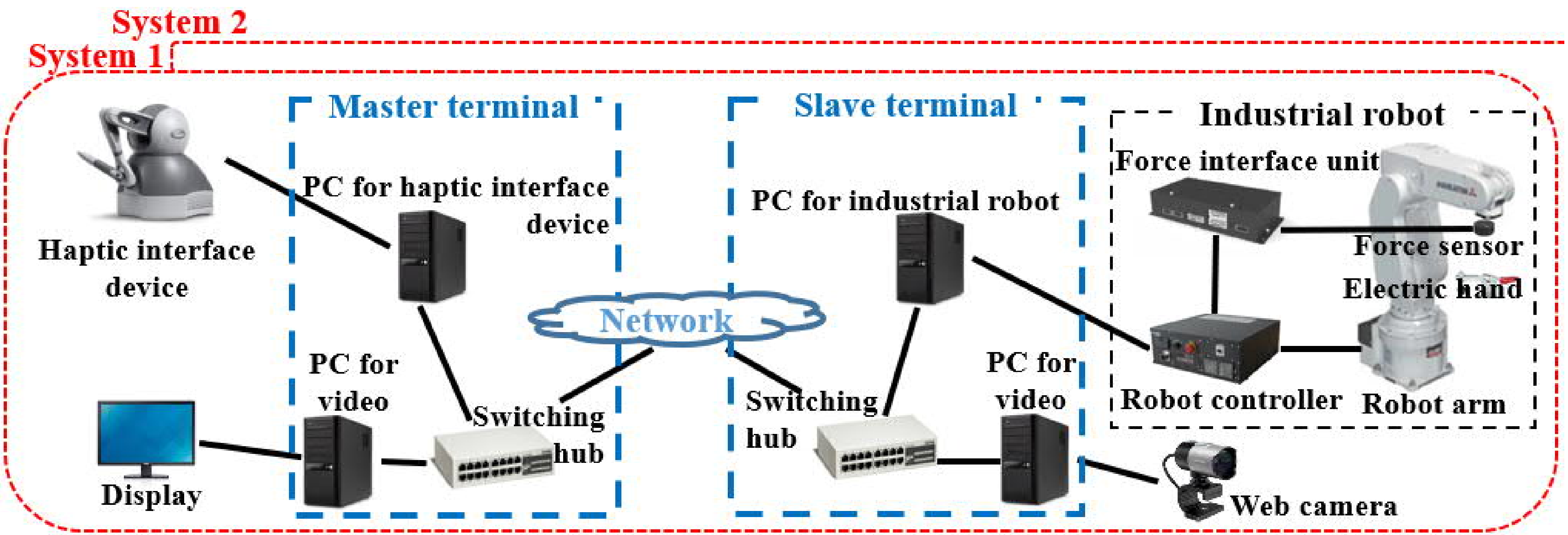
- **Need to make a comparison of cooperative work not only between robot and robot, but also between human and robot.**

# This Work

**We carry out hand delivery as cooperative work between human and robot in two remote robot systems with force feedback in the following two cases.**

- ✓ **Robot-robot case: Two robot arms conduct the work.**
- ✓ **Human-robot case: A human and a robot arm conduct the work.**

# Remote Robot Systems with Force Feedback



# Calculation Method of Position

**Position of robot**

$$\boldsymbol{S}_t = \begin{cases} \boldsymbol{M}_{t-1} + \boldsymbol{V}_{t-1} & (\text{if} |\boldsymbol{V}_{t-1}| \leq V_{\max}) \\ \boldsymbol{M}_{t-1} + V_{\max} \dfrac{\boldsymbol{V}_{t-1}}{|\boldsymbol{V}_{t-1}|} & (\text{otherwise}) \end{cases}$$

$\boldsymbol{S}_t$ : **Position vector of industrial robot at time** $t$

$\boldsymbol{M}_t$ : **Position vector of haptic interface device at time** $t$

$\boldsymbol{V}_t$ : **Velocity vector of industrial robot**

$V_{\max}$ : **Maximum velocity of industrial robot (5mm/ms)**

# Robot Position Control Using Force Information[*2] (1/2)

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

**We move the robot arm in the direction where the force applied to the stick is reduced as follows:**

$$\widehat{\boldsymbol{S}_t} = \boldsymbol{S}_t + P$$

$\widehat{\boldsymbol{S}_t}$ **: New position vector of robot arm at time $t$ (> 0)**

$\boldsymbol{S}_t$ **: Position vector of robot arm calculated by haptic interface device at time $t$ (> 0)**

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

# Robot Position Control Using Force Information (2/2)

*2 S. Ishikawa *et al.*, Proc. WSCE, Dec. 2019.
*3 Q. Qian *et al.*, Proc. ICCC, Dec. 2018.

**When a wooden stick is held by two robot arms, we move the one robot arm by *P*, and measure the force applied to the stick.**[*3]

$$P_x = a_x F_x$$

$P_x$**: Movement distance of the robot arm at $x$ axis**

$F_x$**: Force vector sensed by force sensor at $x$ axis**

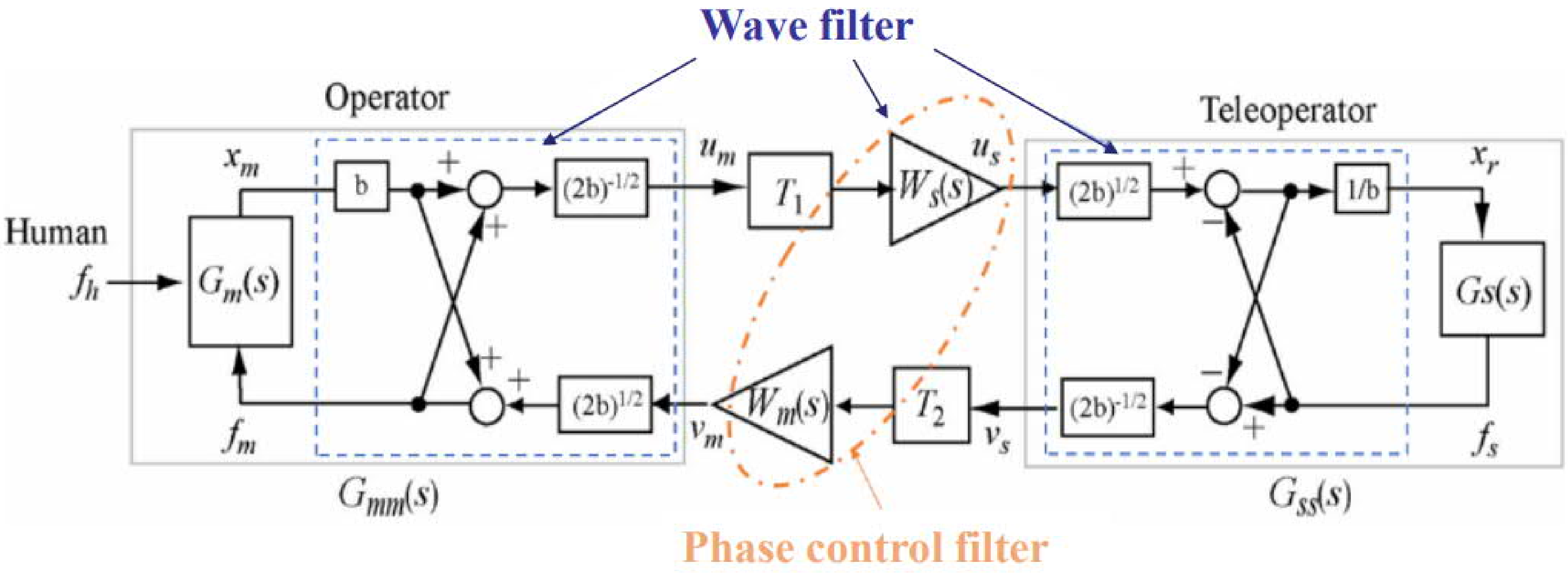
$a_x$ **: Function of length $l$ of the wooden stick**[*2]

$$a_x = 4.82 \times 10^{-2} l - 1.16$$

**We can calculate the difference in the position vector between the two robot arms from the force applied to the stick with length of $l$ [cm].**

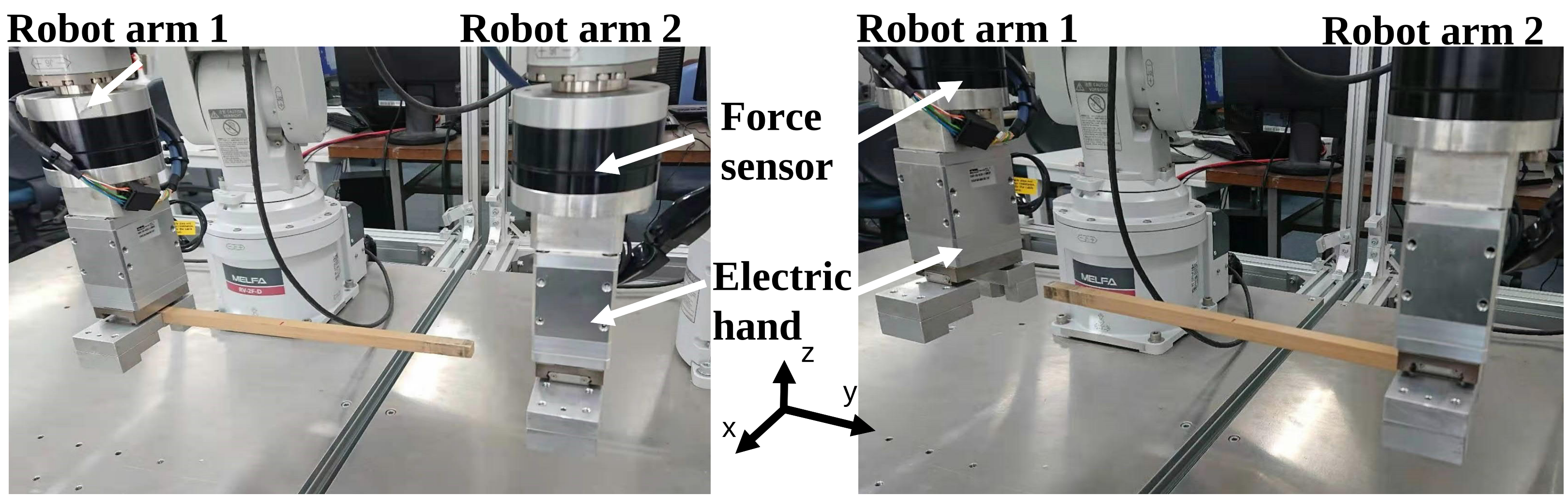
# Stabilization Control with Filters[*3]

*3 P. Huang *et al.*, IJCNS, vol. 12, no. 7, pp. 99-111, July 2019.



# Experiment Method (1/5)

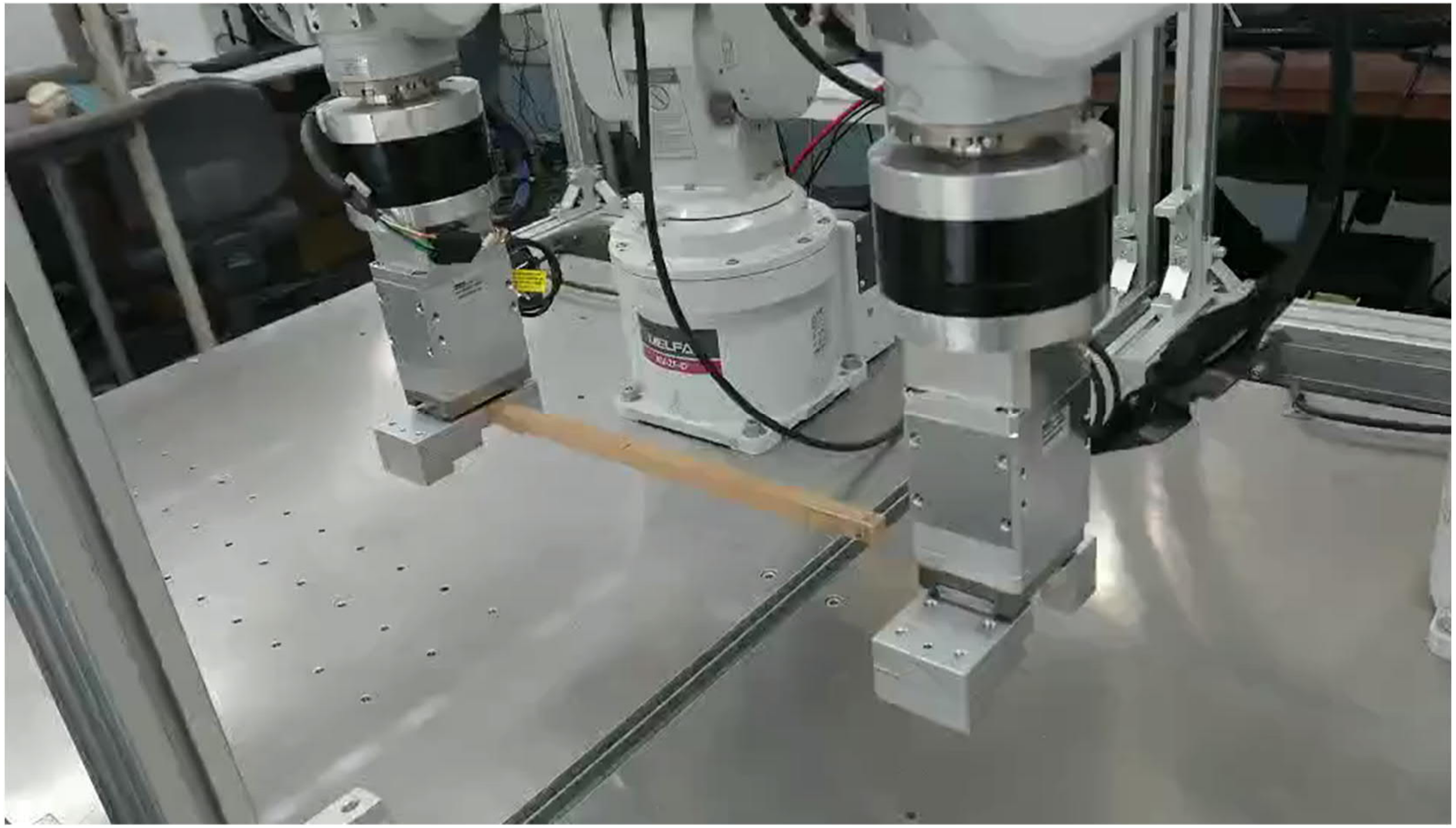
- **Two types of cooperative work**
  - ✓ **Work A**: ***Robot arm 1 passes a wooden stick to robot arm 2 or a reacher which is held by a human.***
  - ✓ **Work B**: ***Robot arm 1 receives the stick from robot arm 2 or a reacher which is held by a human.***
- **Wooden stick: 1 cm × 1 cm × 30 cm (height × width × length)**




Work A

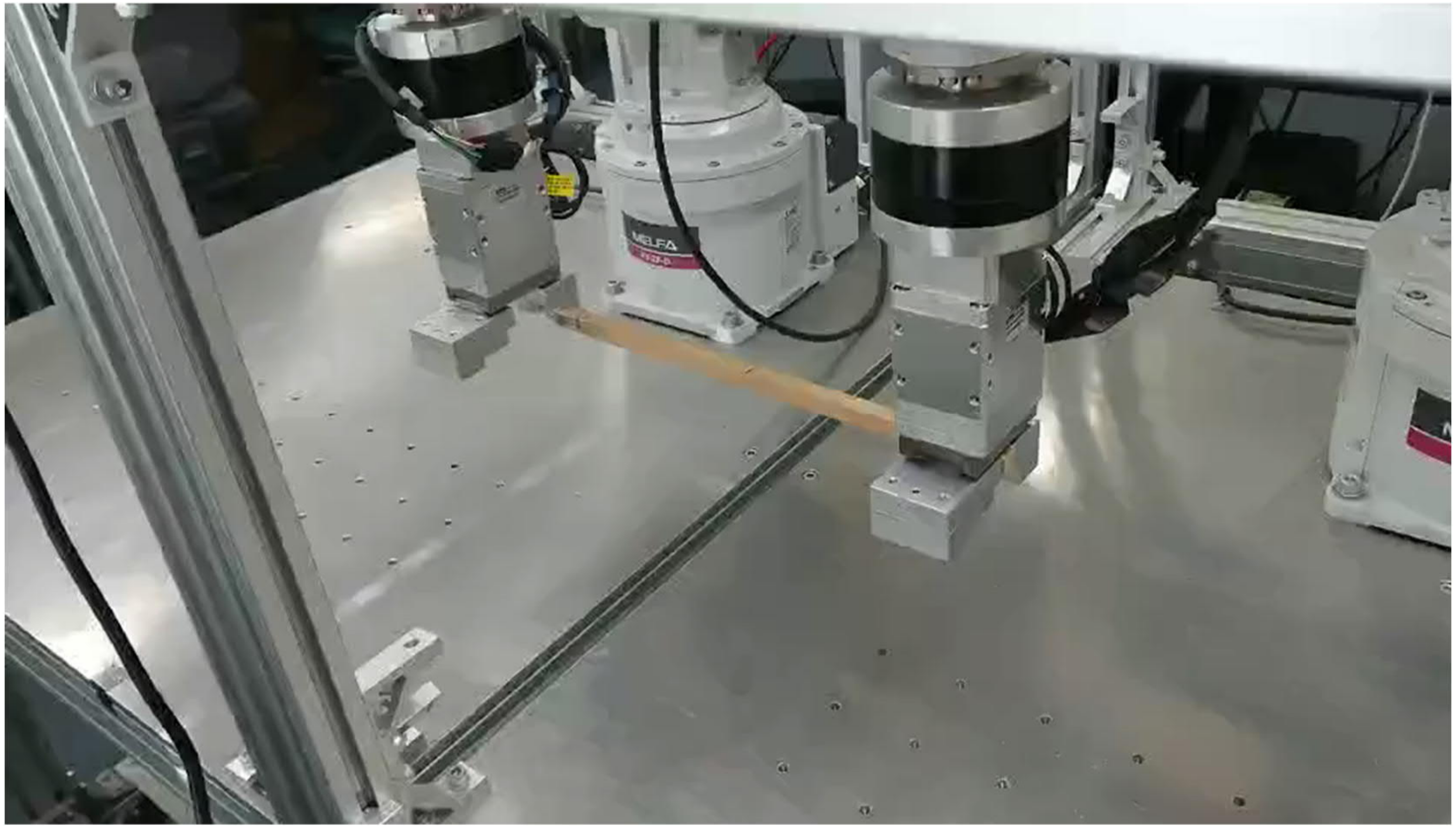
Work B

# Experiment Method (2/5)



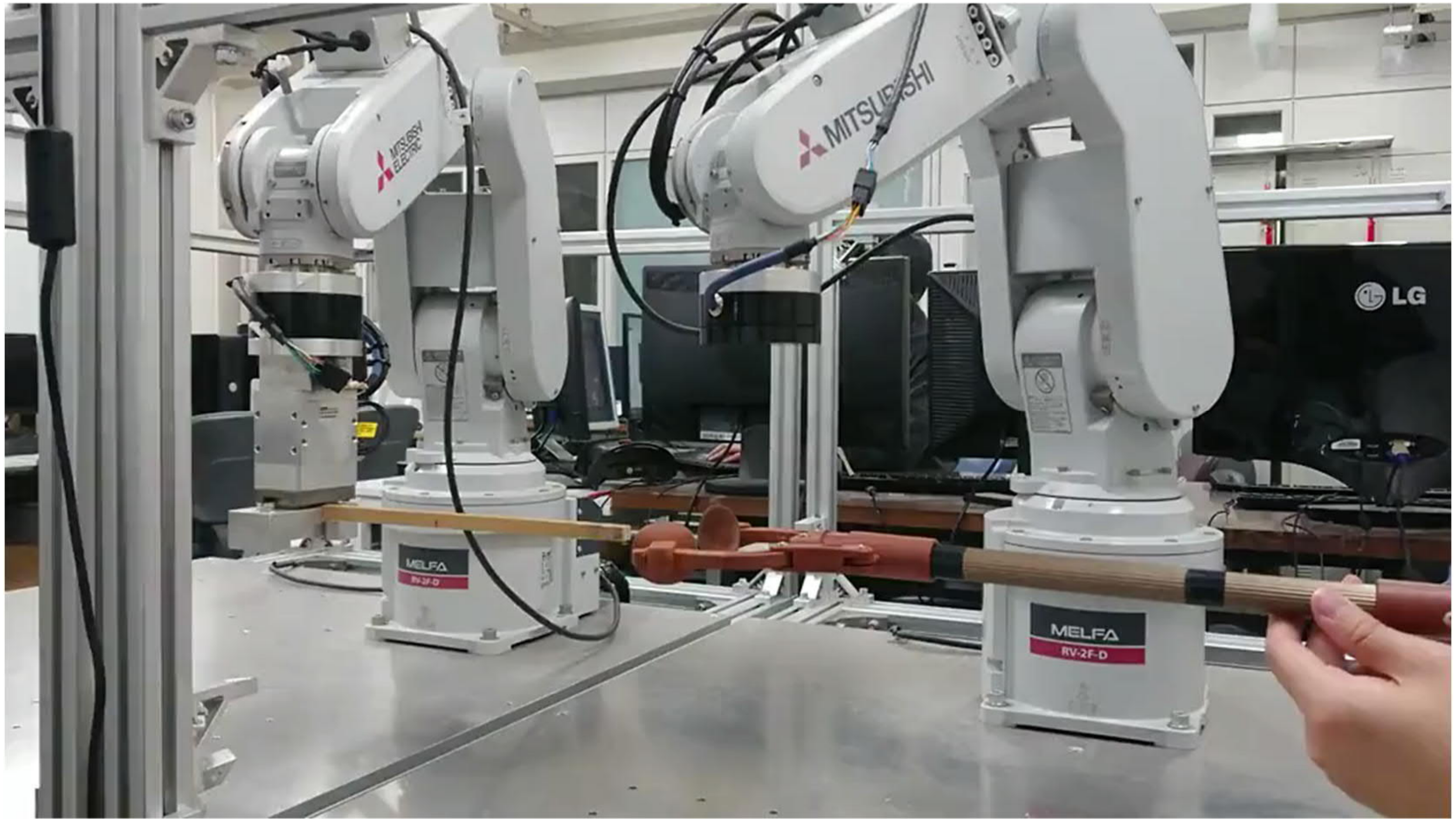
**Work A (robot-robot case)**

# Experiment Method (3/5)



**Work B (robot-robot case)**

# Experiment Method (4/5)




**Work A (human-robot case)**

# Experiment Method (5/5)


**Work B (human-robot case)**

# Experiment Method

▪**The experiment was divided into the following four types according to which types of control were performed:**

① **Without control**

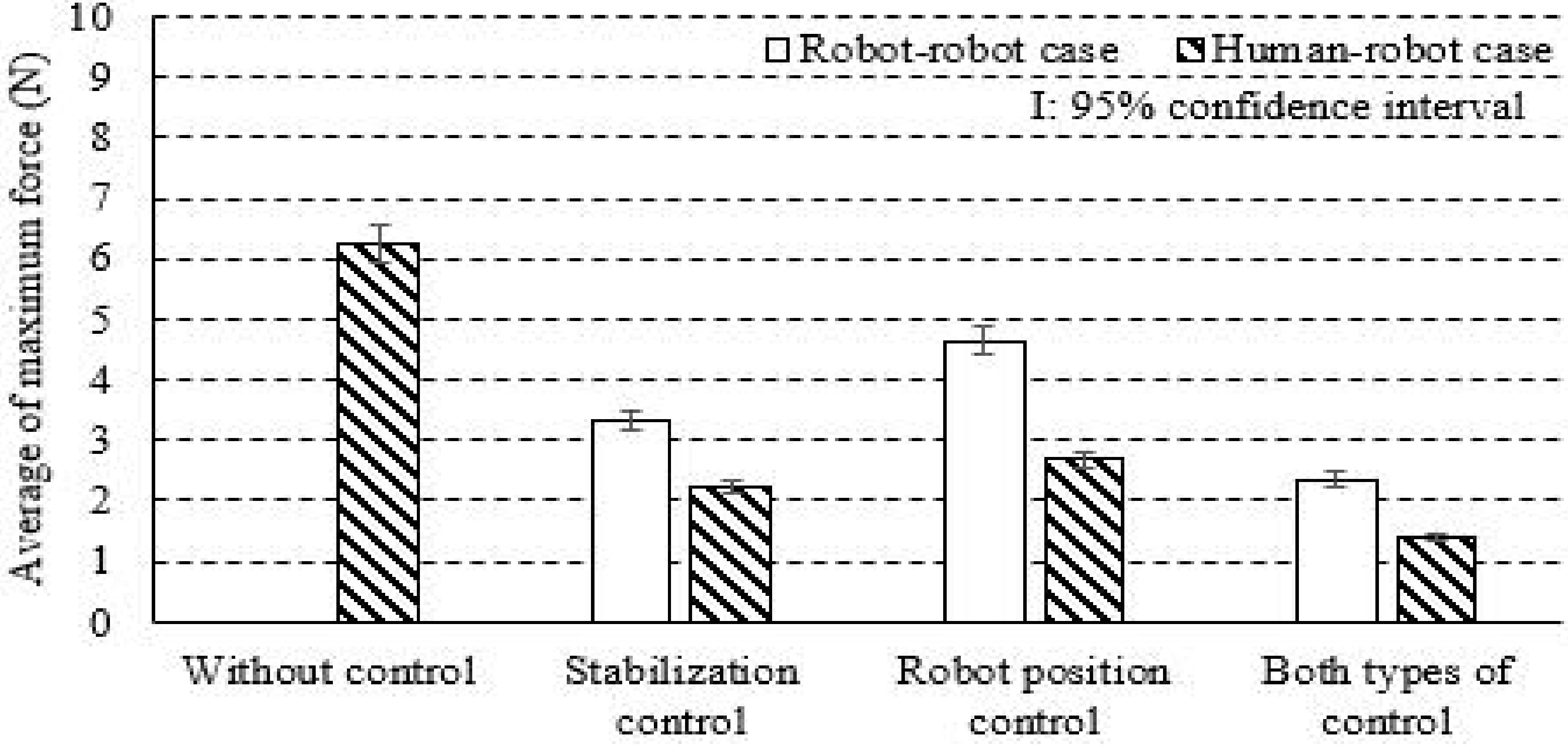
② **Only stabilization control**

③ **Only robot position control**

④ **Both types of control**

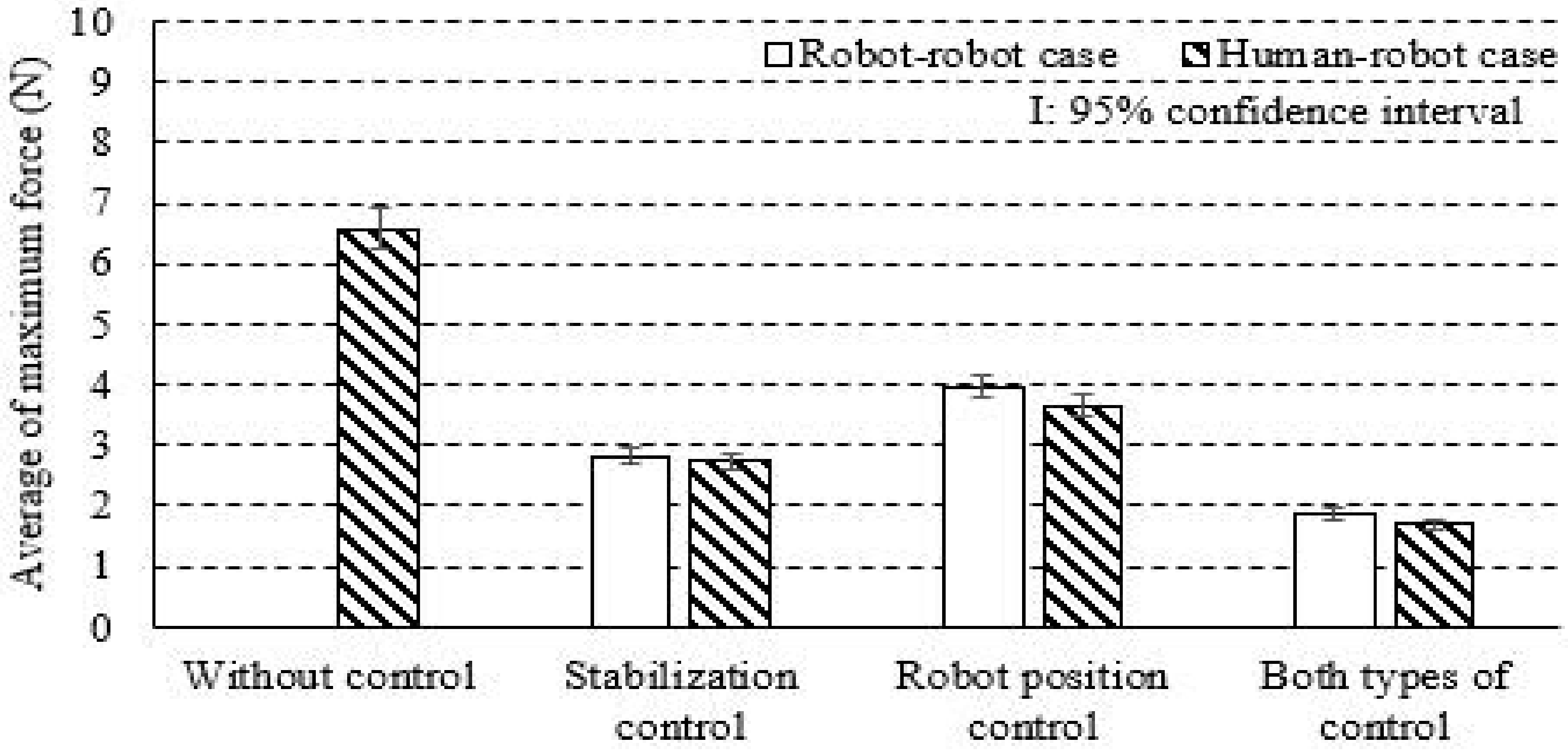
▪**We measured the force applied to the wooden stick.**

# Experimental Results (1/4)



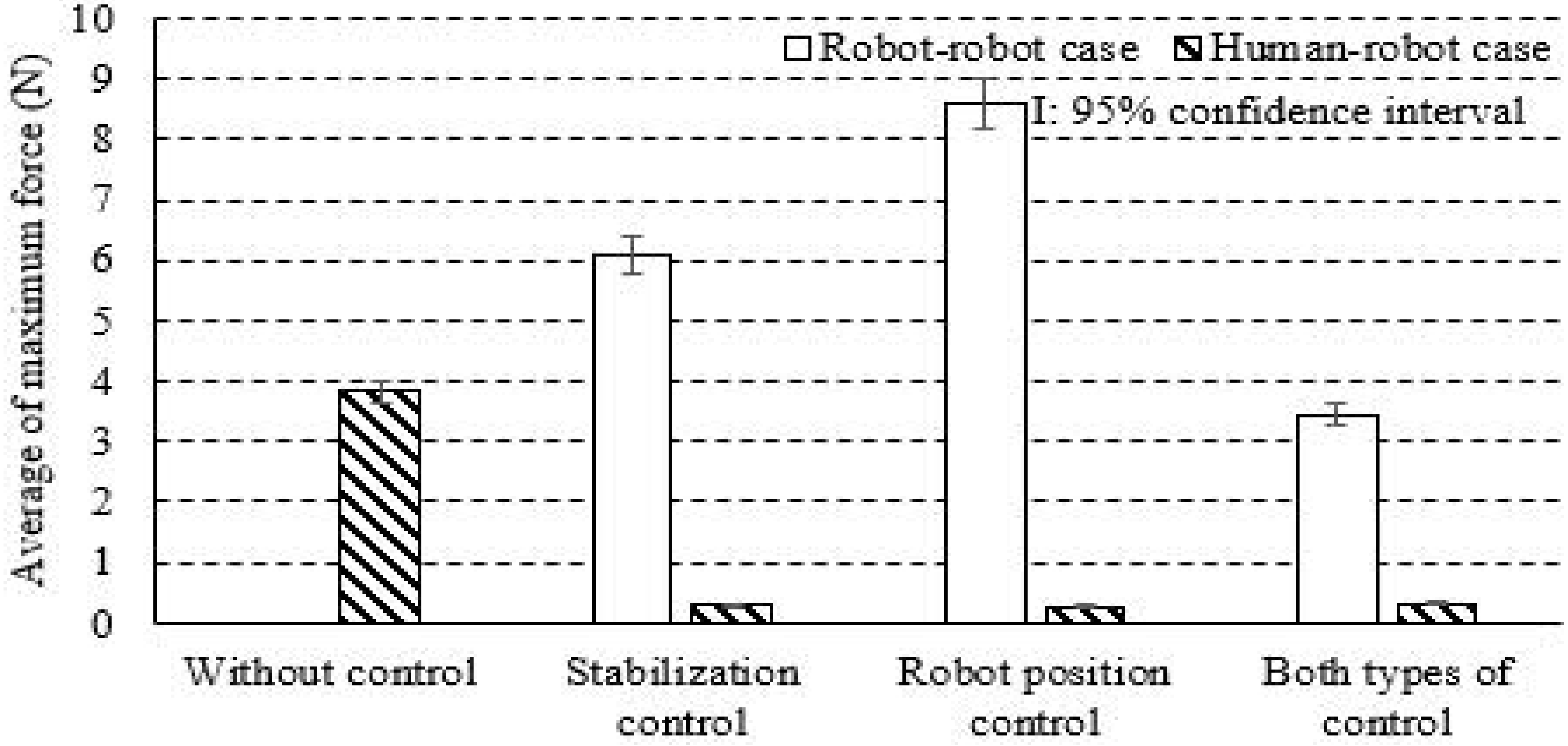

**Work A (*y*-axis direction)**

# Experimental Results (2/4)



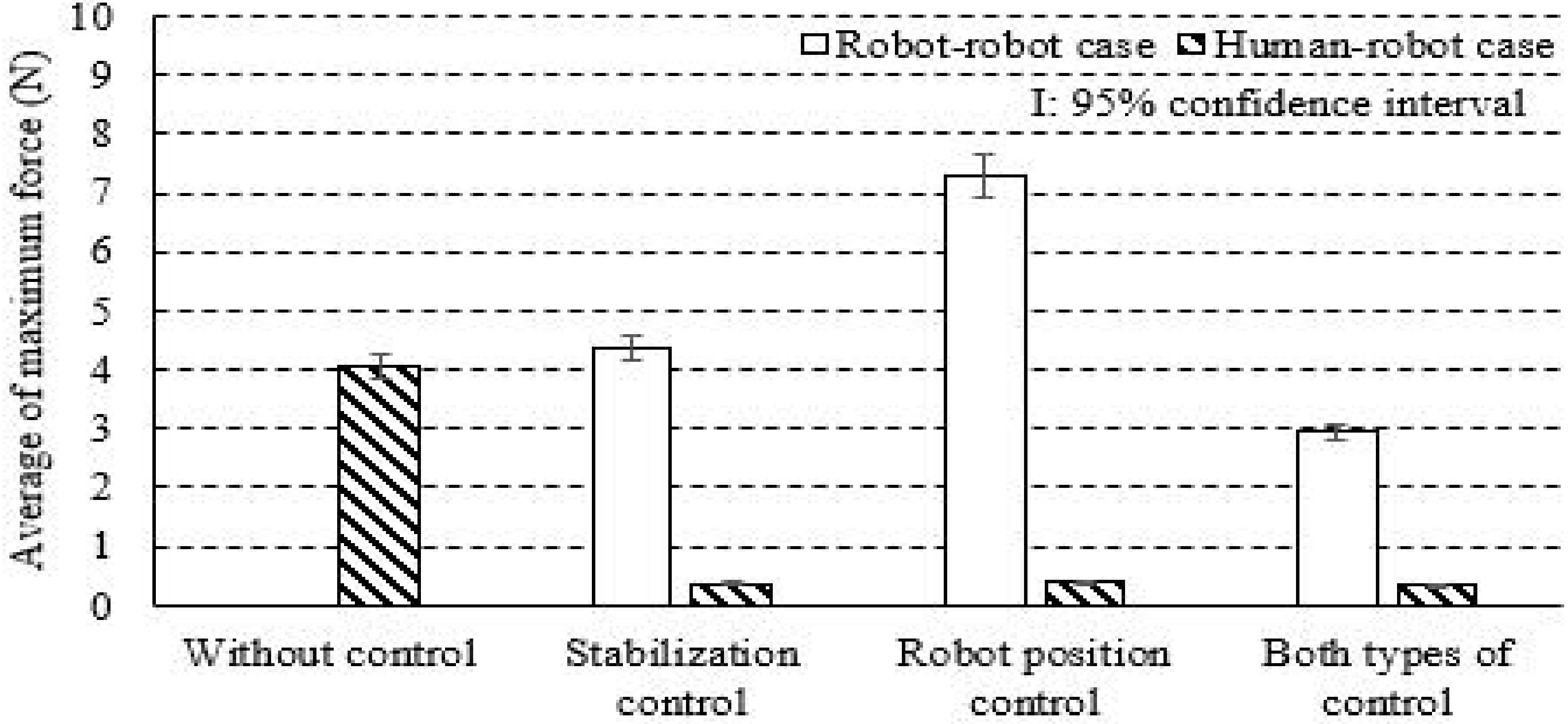

**Work B (*y*-axis direction)**

# Experimental Results (3/4)




**Work A (*x*-axis direction)**

# Experimental Results (4/4)




**Work B (*x*-axis direction)**

# Conclusion

**・We compared the efficiency of hand delivery between the human-robot and robot-robot cases in the remote robot systems with force feedback by experiment.**

**・We compared the effects of the stabilization control by filters and the robot position control using force information.**

↓

**✓ Human-robot case is superior to the robot-robot case.**

**✓ Both types of control should be carried out together.**

# Future Work

- **Reducing the average of maximum force in the robot-robot case to that in the human-robot case.**
- **Dealing with the cooperative work while the robot arms are moving.**