Effect of Neural Network at Server on Robot Position Control Using Force Information

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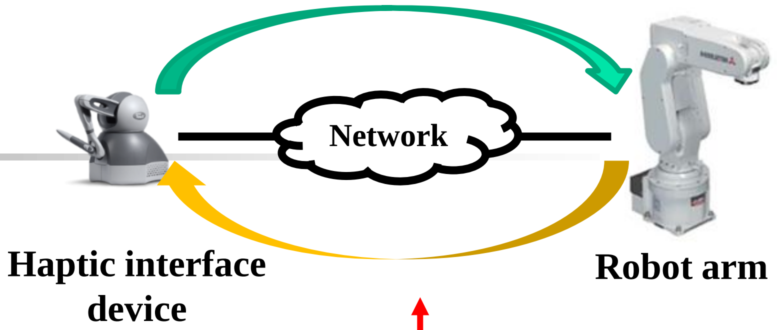
Background (1/2)



Remote robot systems with force feedback have been actively researched.
We can conduct various types of cooperative work by using remote robot systems.

It is possible for users to perceive shapes, weights, and softness of remote objects hit/touched by robots through haptic interface devices (i.e., force feedback).

The efficiency and accuracy of the cooperative work can be expected to improve.

Background (2/2)

When transmitting position/force information over a network like the Internet, in which the quality of service (**QoS**) is not guaranteed

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

Quality of Experience (**QoE**) degradation

Unstable phenomena

QoS control + **Stabilization control** are needed

Previous Work (1/2)

*1 S. Ishikawa *et al*., WSCE, pp. 210-2014, Dec. 2019.

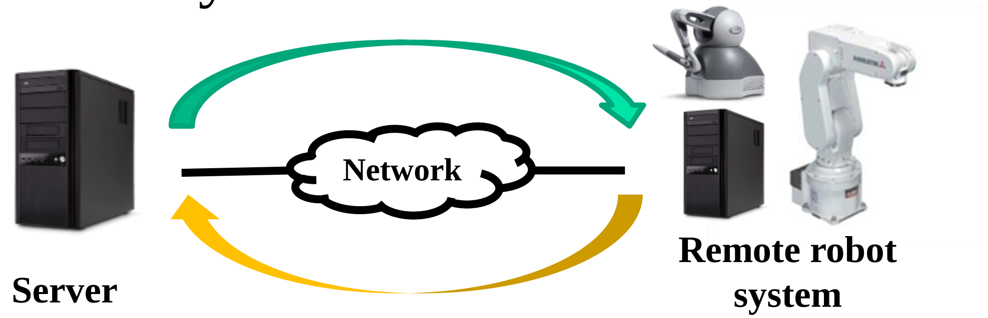
- Applied **robot position control using force information**[*1] to a remote robot system for stable cooperative work (***carrying an object together***).

The position of the robot arm is finely adjusted to reduce the force acting on the object.

- ✓ The control can help the system to carry the object smoothly without large force.
- ✓ There are the optimal adjustment value for **each object length**.
- ✓ The value depend on the characteristics of the object.

Previous Work (2/2)

It is important to take account of **various factors** such as object material, object length, velocity, and task contents to further enhance the efficiency of the control.



➡ By sending **above information** to a **server** (or cloud) which analyzes and calculates **the optimal adjusted value**, high-efficient QoS control can be achieved.

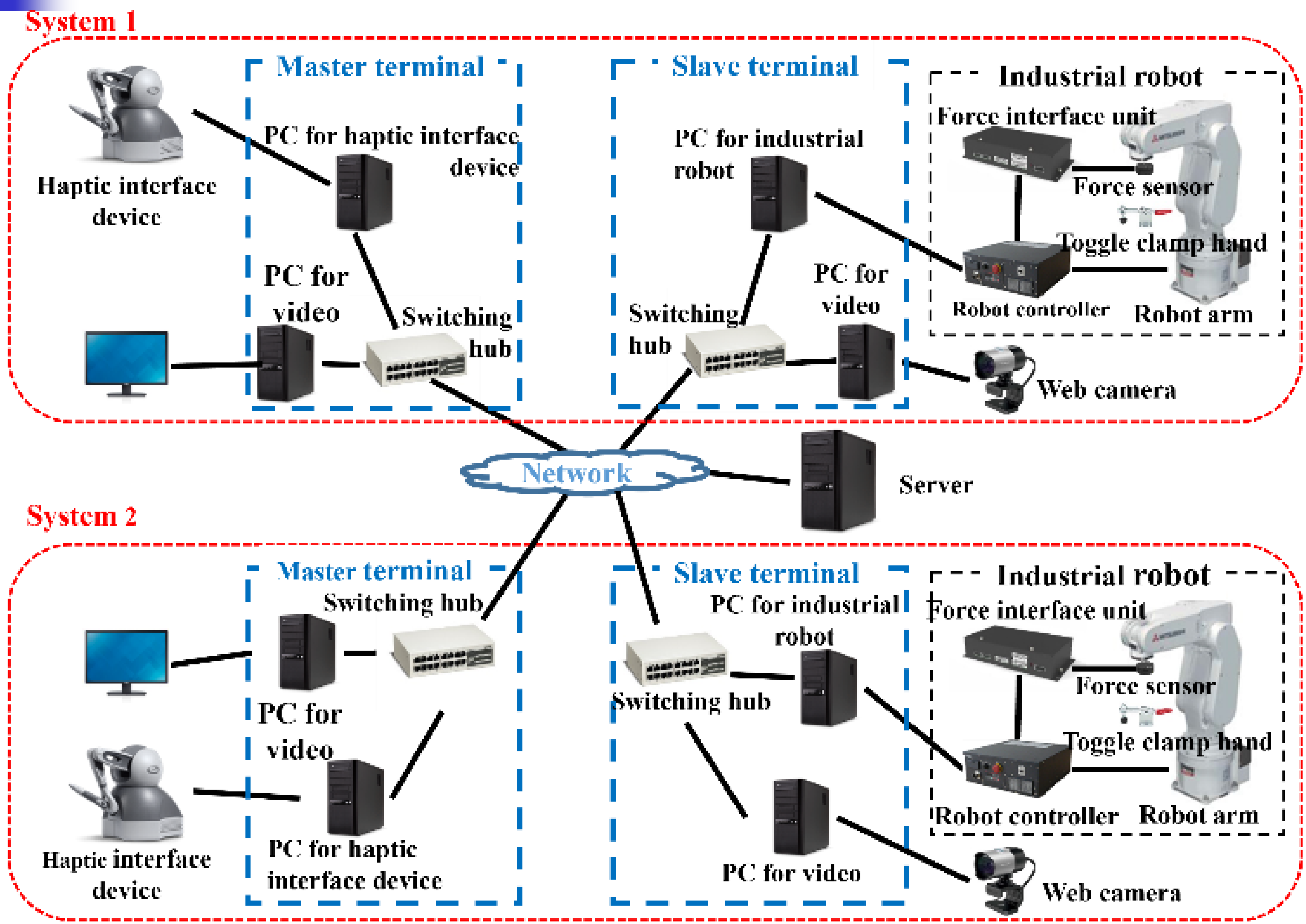
Leveraging AI technology such as neural network is believed to enable even higher precision control. No experiments are conducted.

Purpose

This work

We **explore the effectiveness of employing a neural network at a server** for the QoS control in the remote robot systems with force feedback and **investigate the influence of network delay** on the control through experiments.

Remote Robot Systems with Force Feedback



Configuration of two remote robot systems with force feedback

Robot Position Control Using Force Information (1/2)

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

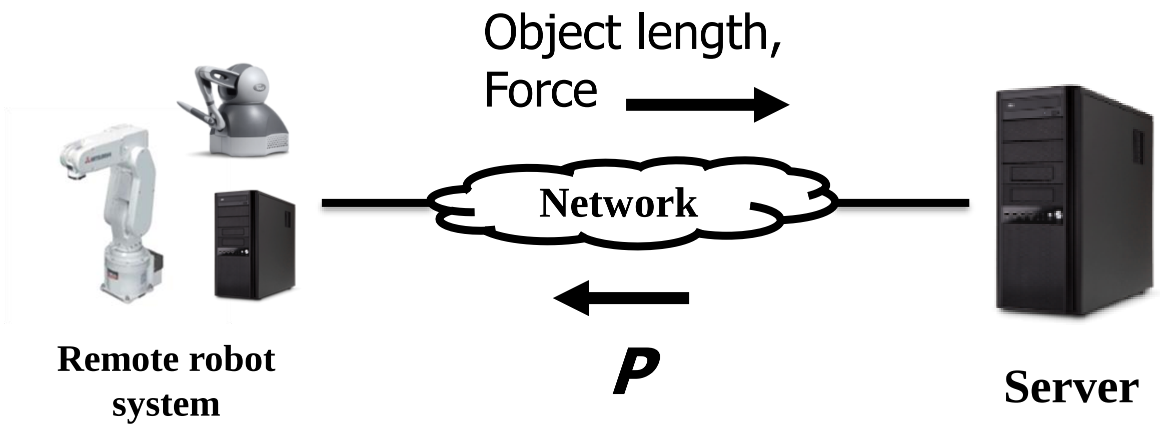
adjust the position so that the force applied to the object becomes smaller

$$\boldsymbol{P} = (4.82 \times 10^{-2} l_{opt} - 1.16)\boldsymbol{F}$$

- $\hat{\boldsymbol{S}}_t$: Estimated position vector of industrial robot at time t ($t \geq 1$)
- $\boldsymbol{S}_t$: Position vector of industrial robot at time t
- $\boldsymbol{P}$: Position adjustment vector
- $\boldsymbol{F}$: Sensed force
- l_{opt} : Variable depending on length of object

The above calculation is performed at the server.

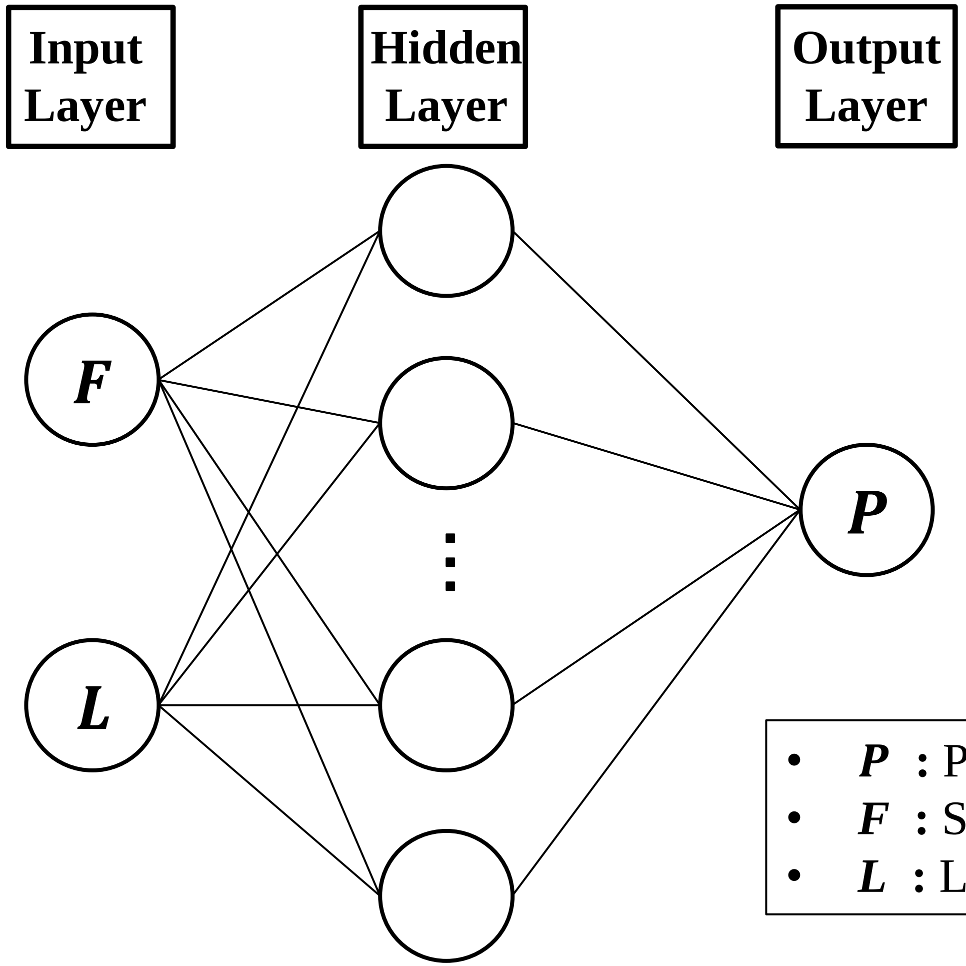
Robot Position Control Using Force Information (2/2)



- Each remote robot systems sends values of **object length** and **force**.
- The server calculates and sends back the ***P*** value **using a neural network**.

Neural Network Configuration (1/2)

*2 Y. Zhang *et al.*, ICICN, pp. 545-549, Nov. 2021.



- ***P*** : Position adjustment vector
- ***F*** : Sensed force
- ***L*** : Length of object

The number of neurons in the **Hidden Layer** is set to 25. *2

Neural Network Configuration (2/2)

Training Data and Validation Data for neural network

	F_x (N)	L (cm)	l_{opt} (cm)	P_x (mm)
Training Data	-6~6	30	55	Calculated by equation.
		40	76	
		60	150	
Validation Data		45		

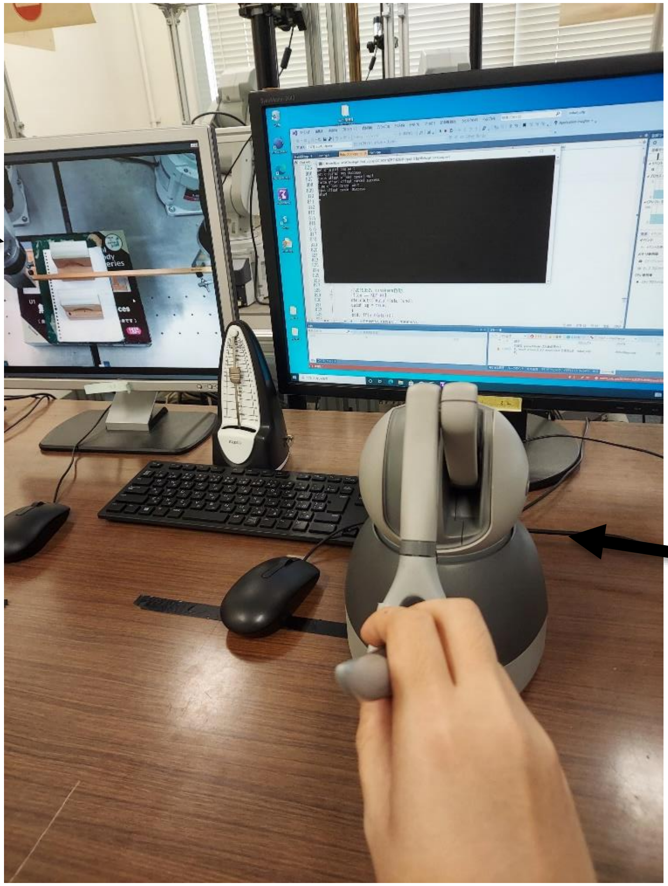
$\boldsymbol{F_x}$: $\boldsymbol{F}$ in $x-axis$ direction
$\boldsymbol{P_x}$: $\boldsymbol{P}$ in $x-axis$ direction

The force $\boldsymbol{F_x}$ in the training data spans from −6 N to 6 N.
The values of $\boldsymbol{P_x}$ is obtained from the equation.

The length of 45 cm is used for the experiment.

Experiment Method (1/4)

Video

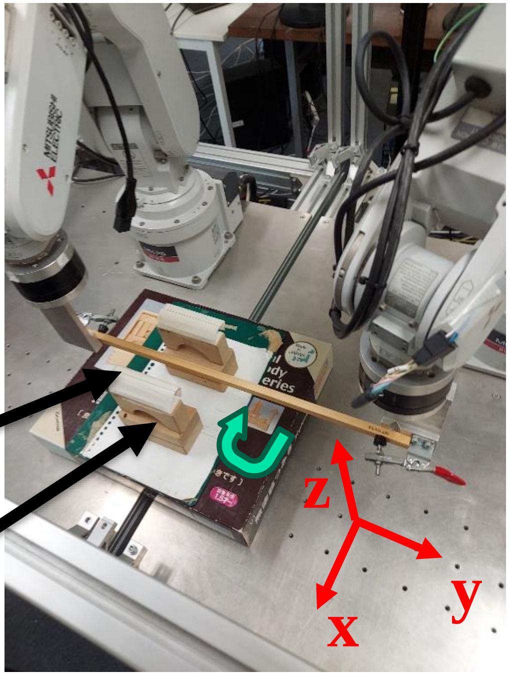


Haptic interface device of system 2

A single user operated **a haptic interface device** with his/her hand while watching video.

Experiment Method (2/4)

Robot arm of system 2 (Human operation)



Robot arm of system 1 (Automatically operation)

Paper block

Building blocks

- The user moved the stick toward the paper blocks to be touched while keeping the robot arms parallel to each other.

- To move the stick at almost the same velocity, he/she touched the first paper block at about **6** seconds from the beginning of each work and the second paper block at about **12** seconds.

Experiment Method (3/4)

<u>Experiment (1)</u>

- **Verification of control effectiveness**

- The server output **the Position adjustment vector** from neural network and then sent the value back to System **(**called **NN)**
- Using Robot Position Control Using Force Information with 40 cm and 60 cm l_{opt} value **(**called $\boldsymbol{l_{opt}}$ **40 and** $\boldsymbol{l_{opt}}$ **60)**
- Not using any controls **(**called **NC)**
- The **average** and **maximum** values of the absolute force applied to the wooden stick were measured during each operation, and the averages of these values over the **10 trials** were calculated for each cases (referred to as **the average of average force** and **the average of maximum force.**

Experiment Method (4/4)

*3 M. Carson *et al*., ACM SIGCOMM. 33 3, pp. 111-126, July 2003.

Experiment (2)

▪ **Investigation of the influence of network delay**

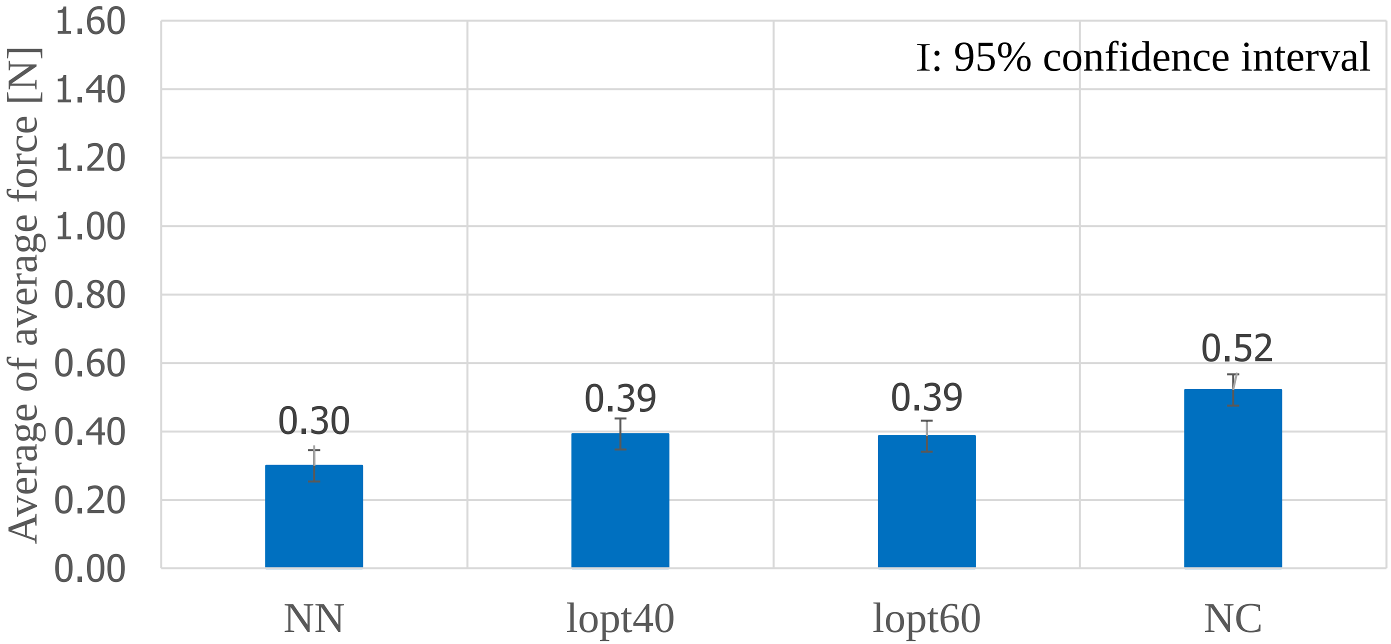
- Set the one-way constant delay (called the ***additional delay***) for each packet transmitted between system and the server by using a network emulator (NIST Net [*3]).

- The server output **the Position adjustment vector** from neural network and then sent the value back to System 2.

- The **average** and **maximum** values of the absolute force applied to the wooden stick were measured during each operation, and the averages of these values over the **10 trials** were calculated. (referred to as **the average of average force** and **the average of maximum force.**

Experimental Results (1/4)

Experiment (1) Average of average force

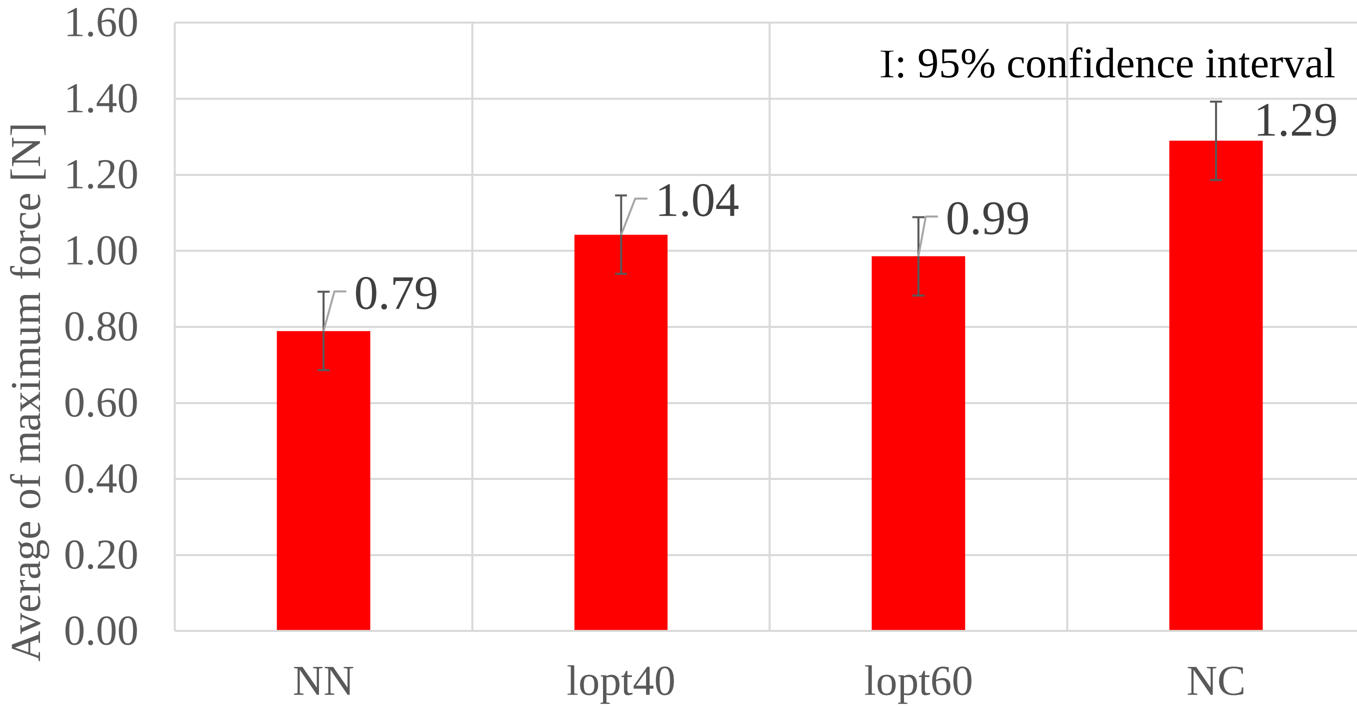


- **NN has the smallest** average of average force.
- l_{opt} 40 yields nearly identical averages as l_{opt} 60, both ranking the second smallest.

➡ **Control using the neural network is the most effective.**

Experimental Results (2/4)

Experiment (1) Average of maximum force

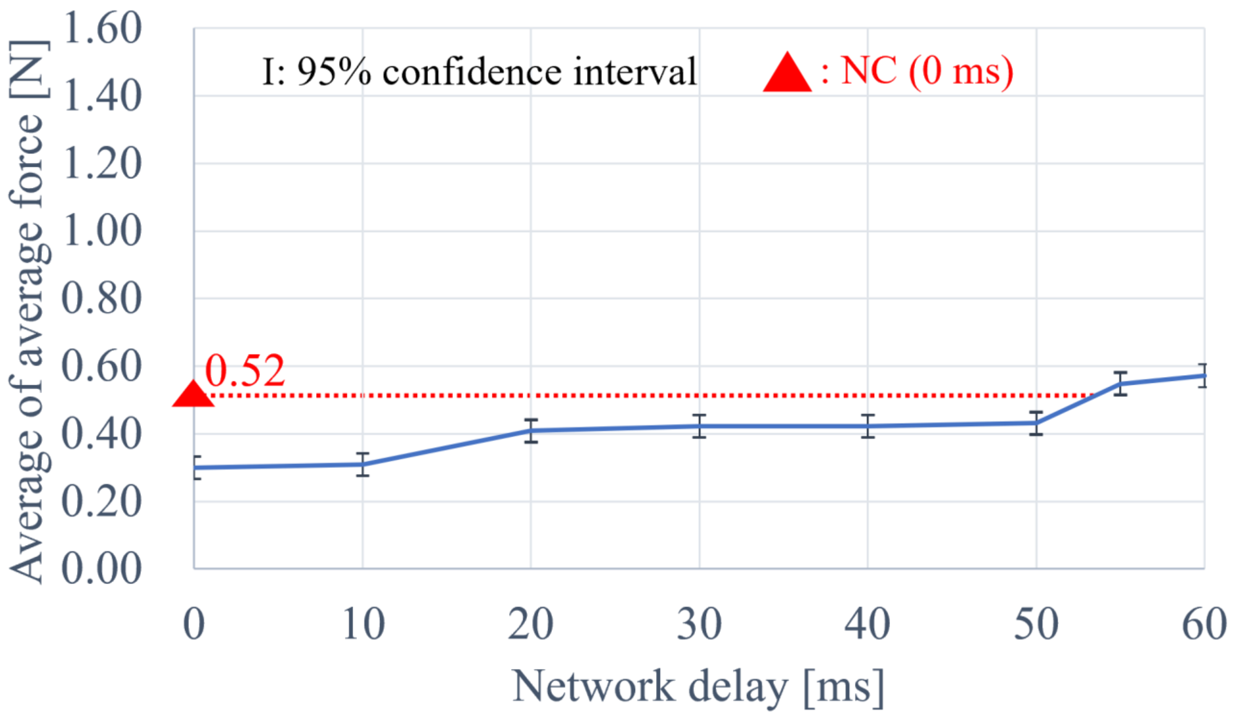


- **NN has the smallest** average of maximum force.
- l_{opt} 60 has the second smallest, followed by l_{opt} 40.

Control using the neural network is the most effective.

Experimental Results (3/4)

Experiment (2)
Average of average force

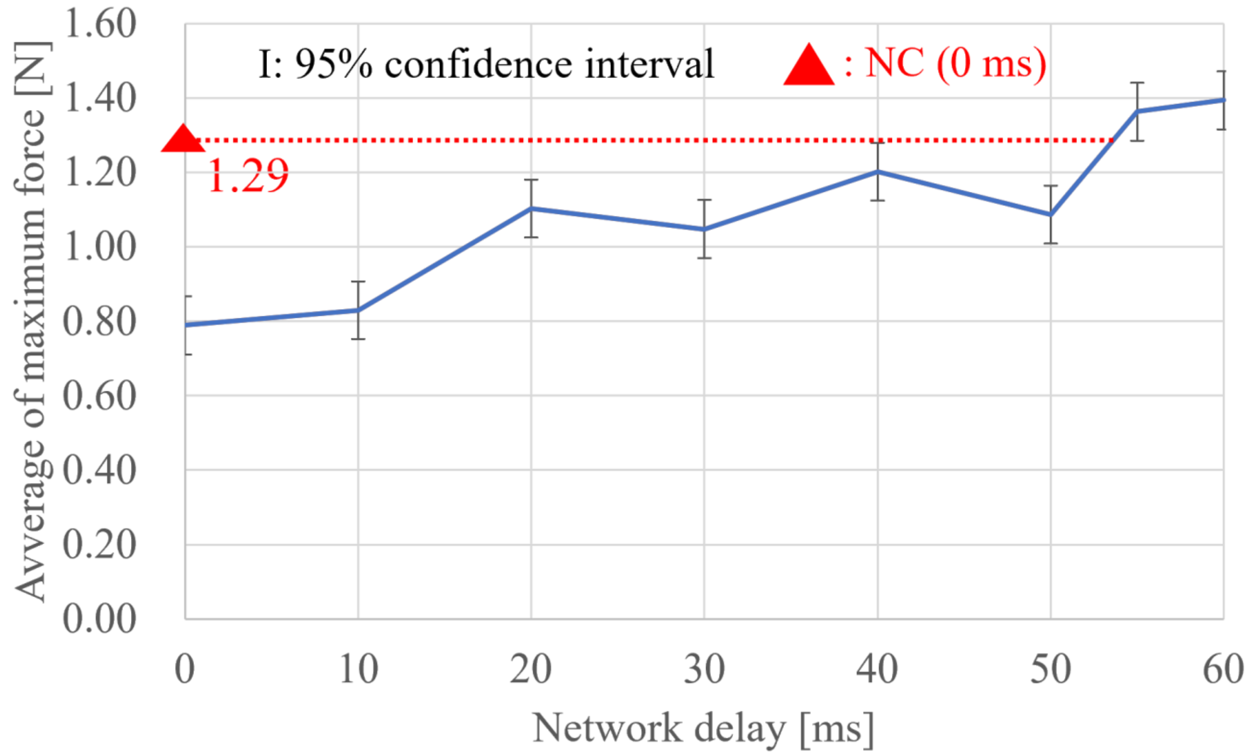


- The average of average force increase as the additional delay becomes **larger**.
- The force applied to the wooden stick is **reduced** by **robot position control** until the additional delay of **55 ms.**

Experimental Results (4/4)

Experiment (2)

Average of maximum force



- The average of maximum force increase as the additional delay becomes **larger**.
- The force applied to the wooden stick is **reduced** by **robot position control** until the additional delay of **55 ms.**

Conclusion

- We investigated the effect of using a neural network at a server for one type of QoS control by experiment.
- We examined the influence of network delay.

The control using a neural network effectively reduces the force exerted on the wooden stick, when the network delay is **less than or equal to about 55 ms.**

Future work

- We intend to extend the neural network at the server to other types of QoS control as our future research.