Influence of Network Delay on QoS Control Using Neural Network in Remote Robot Systems with Force Feedback

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Background (1/2)

Remote robot systems with force feedback have been actively researched.

By using a haptic interface device, we can feel the shape, softness, surface smoothness, and weight of a remote object which is touched by the robot arm with a force sensor.

The efficiency and accuracy of work can largely be improved.

Background (2/2)

When the force information is transferred over the Internet, which does not guarantee the **Quality of Service (QoS)**

Network delay, delay jitter and packet loss

QoE (Quality of Experience) degradation

- **QoS (Quality of Service) control**
- **Stabilization control**

In order to improve the efficiency of QoS control

We use big data, cloud computing, and AI (Artificial Intelligence) technologies.

Previous Work

➢ **Two remote robot systems with force feedback are used to handle cooperative work of moving an object together.**

➢ **The robot position control using force information as QoS control[*3] is applied to the system.**

- **There is the optimum value for position adjustment according to the force and the length of the object.**
- **The force applied to the object is the minimum at the optimum value.**

It is difficult to find the optimum value for position adjustment according to many factors (e.g., shape, softness, weight, movement speed…) of the object.

Purpose

Big data, cloud computing, and AI technologies can be useful methods for efficient control.
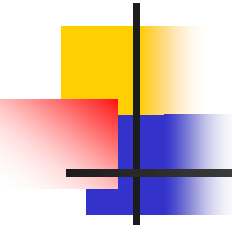
- **Because we transmitted the data over a network, it is important to clarify the influences of *cloud delay* (i.e., network delay and processing time).**

This work

> **We investigate the influence of *cloud delay* on the remote robot systems while using big data, cloud computing, and AI technology by experiment.**

> **We use the optimum value which can be considered as the prediction results from AI technology for the robot position control using force information.**

# QoS Control with Neural Network (1/2)
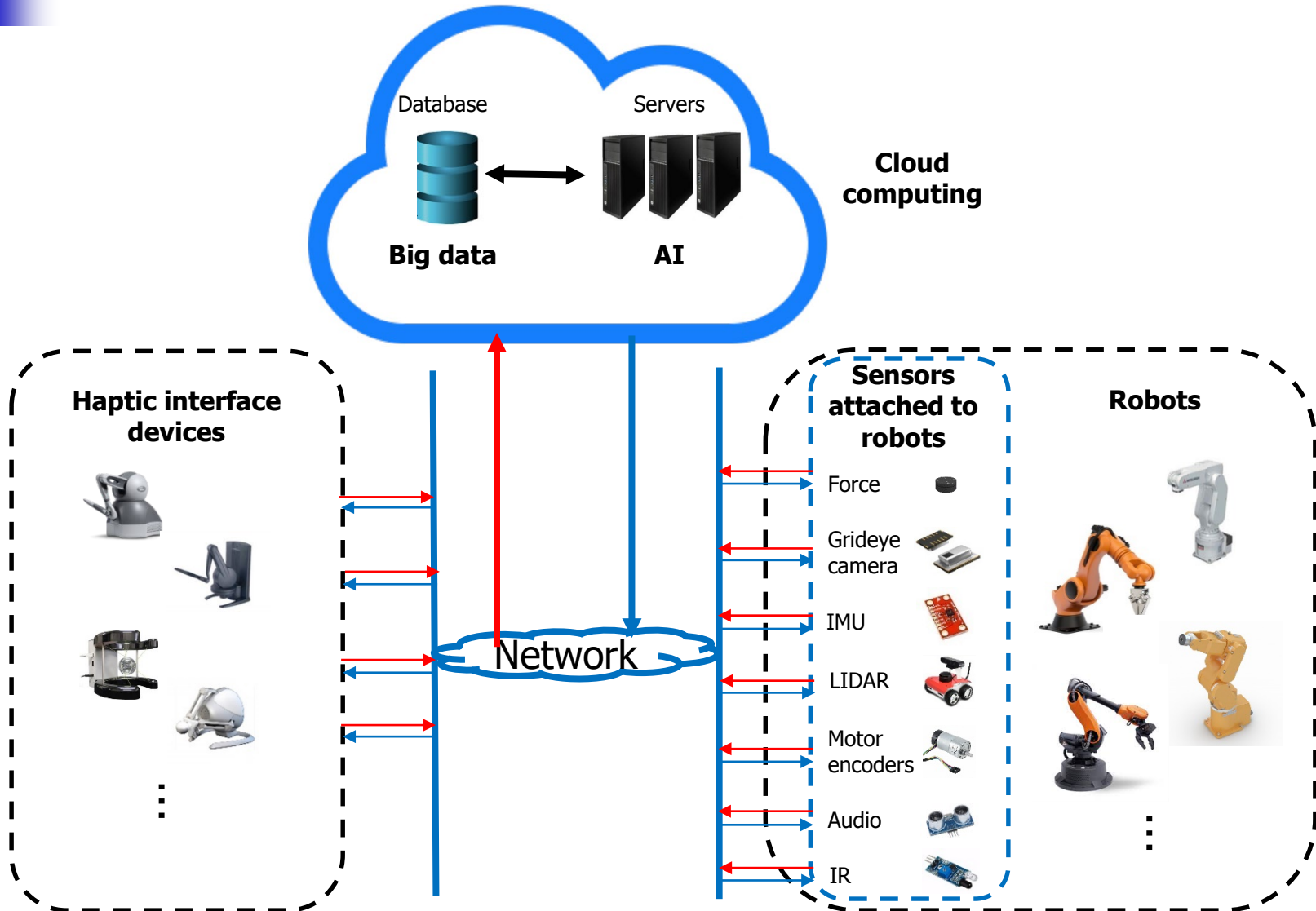
QoS Control with Neural Network (2/2)

➢ **Apply to big data, cloud computing, and AI technologies to the robot position control using force information as QoS control.**

➢ **Investigate the influence of cloud delay while using big data, cloud computing, and neural network by taking account of following two parameters (that is the force applied to an object and the length of the object).**

➢ **Employ the prediction results of position adjustment from neural network to investigate the delay influences.**

Remote Robot System with Force Feedback
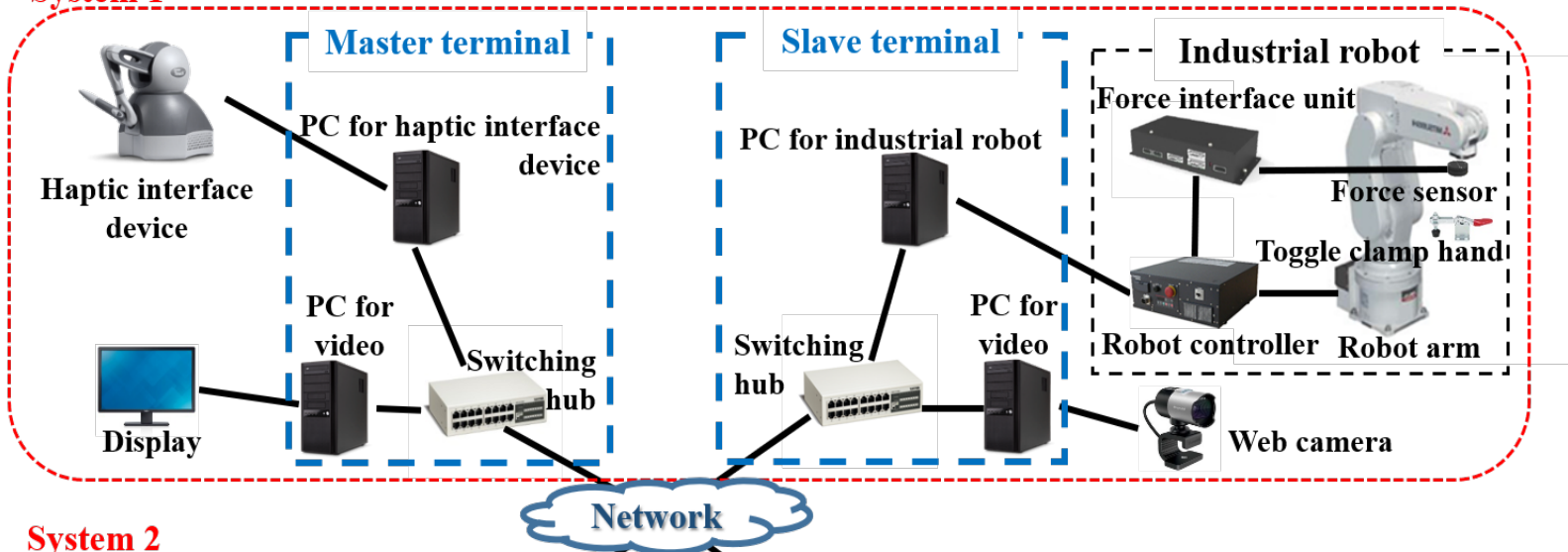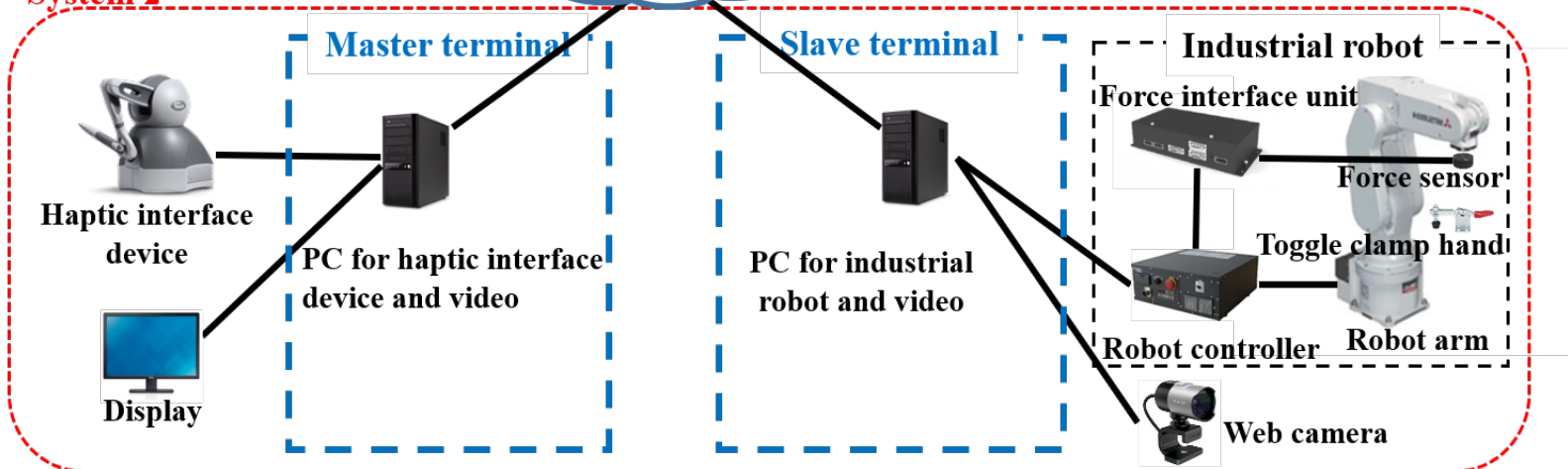
Reaction Force

> **Reaction force output at master terminal**

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

$F_t^{(\mathrm{m})}$: **Reaction force is output at master terminal at time t (>0)**

$F_t^{(\mathrm{S})}$: **Force received from slave terminal at time t (>0)**

K_{scale} : **Coefficient (0.33[*3]) multiplied to force of slave terminal at time t (>0)**

Robot Position

Position of robot arm

$$S_t = \begin{cases} \boldsymbol{M}_{t-1} + \boldsymbol{V}_{t-1} & (\text{if } |\boldsymbol{V}_{t-1}| \leq V_{\max}) \\ \boldsymbol{M}_{t-1} + V_{\max}\dfrac{\boldsymbol{V}_{t-1}}{|\boldsymbol{V}_{t-1}|} & (\text{otherwise}) \end{cases} \qquad (2)$$

S_t: **Position vector S_t of robot arm at time t (> 0)**

M_t: **Position vector of haptic interface device received by slave terminal from master terminal at time t (> 0)**

V_t: **Velocity of robot arm at time t (> 0)**

$V_{\max}$: **Maximum movement velocity (5mm/ms[*4]) of robot arm**

Cooperation between Two Systems

➤ **A user operates two haptic interface devices to carry a wood together by both hands.**
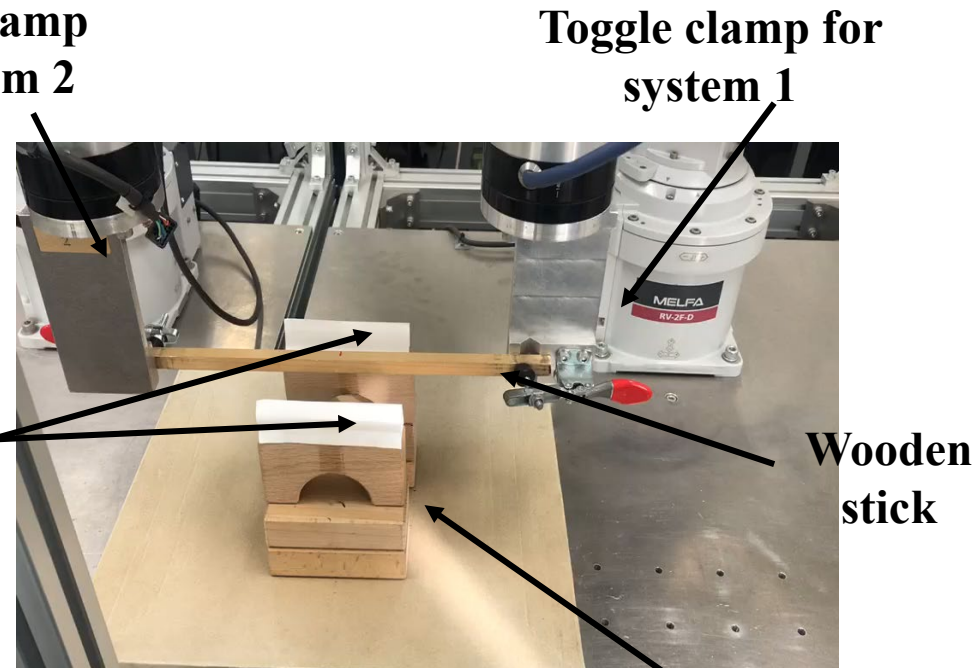
➤ **Stabilization control with filters[*2] is carried out.**
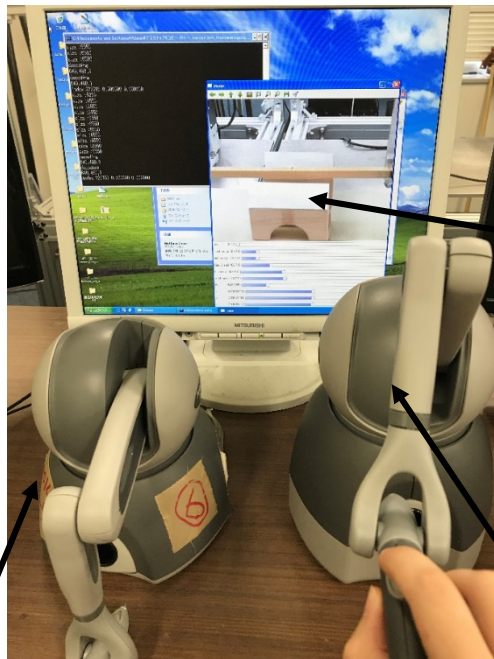
Toggle clamp for system 2

Toggle clamp for system 1

PC for video

Paper blocks

Wooden stick

Haptic interface device of system 1

Haptic interface device of system 2

Wooden blocks

Robot Position Control Using Force Information (1/2)

➢ **The robot position control using force information finely adjusts the robot position to reduce the force applied to the wooden stick.**

➢ **The adjusted position vector $\widehat{S}_t$ of the robot arm at time t (> 0) is obtained by**

$$\widehat{S}_t = S_t + P \qquad (3)$$

S_t: **Position vector obtained by equation (2).**

P: **Position vector which reduces forces between the position vectors of the two robot arms.**

Robot Position Control Using Force Information (2/2)

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

> **Calculation method of P_x *3 (*x*-axis of P)**

$$P_x = \left(4.82 \times 10^{-2} l_{\text{opt}} - 1.16\right) F_x \qquad (4)$$

$$l_{\text{opt}} = 20.105 e^{0.0334L} \qquad (5)$$

F_x: **Force in *x*-axis**

l_{opt}: **Optimum value of position adjustment for wooden stick's length**

L: **Length of wooden stick**

Experiment Method (1/2)

➢ **The two remote robot systems were used to move a wooden stick as an object cooperatively.**

- **Robot arm of system 1: Operated automatically without haptic interface device**
- **Robot arm of system 2: Operated manually with haptic interface device**

➢ **We added a constant delay as the cloud delay for each request of the optimum value from clouds and used the optimum value of position adjustment which we clarified in our previous studies[*3] instead of using neural network and cloud computing.**

Experiment Method (2/2)

➢ **The cloud delay was changed from 0 sec. to 2.5 sec. in random order.**

➢ **The operation was performed 20 times for each cloud delay.**

➢ *Average of average force:* **the averages of the average forces applied to the wooden stick during the 20 operations.**

➢ *Average of maximum force*: **the averages of the maximum forces applied to the wooden stick during the 20 operations.**
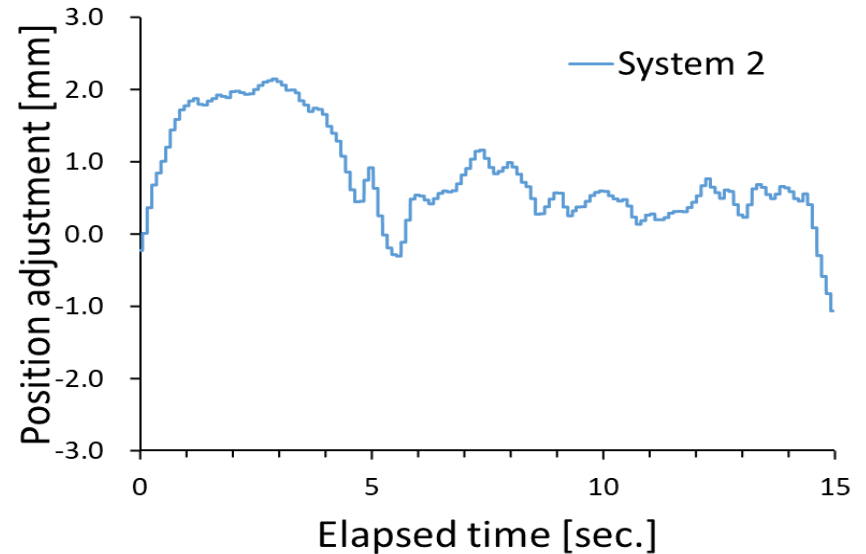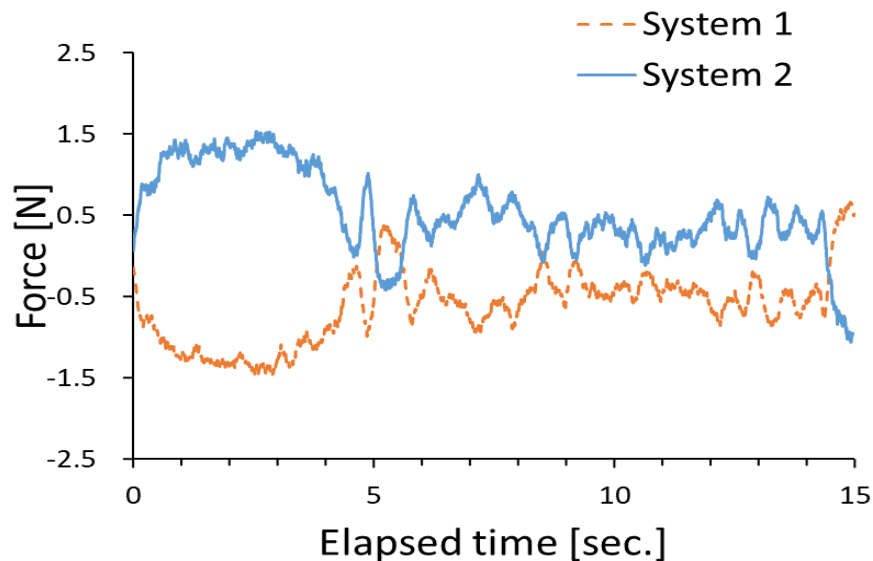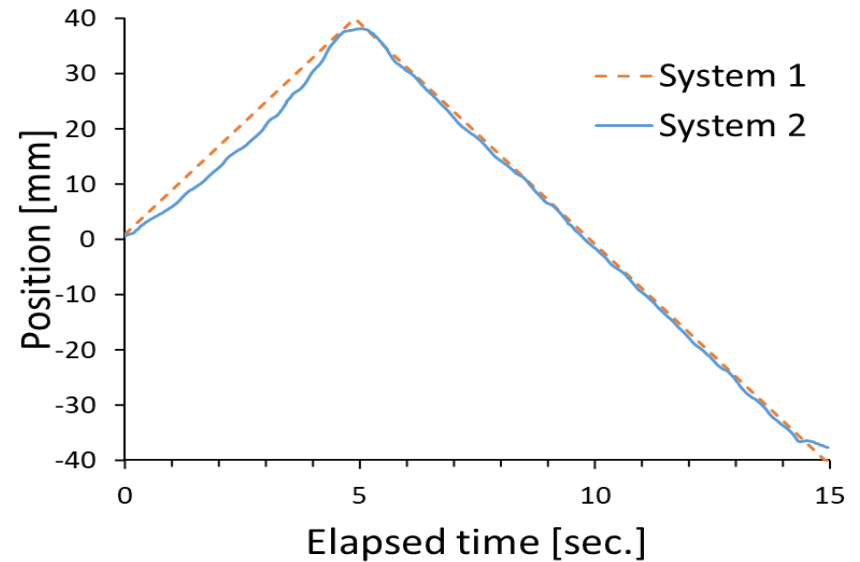
Experimental Results (1/3)

▲ **Without control**
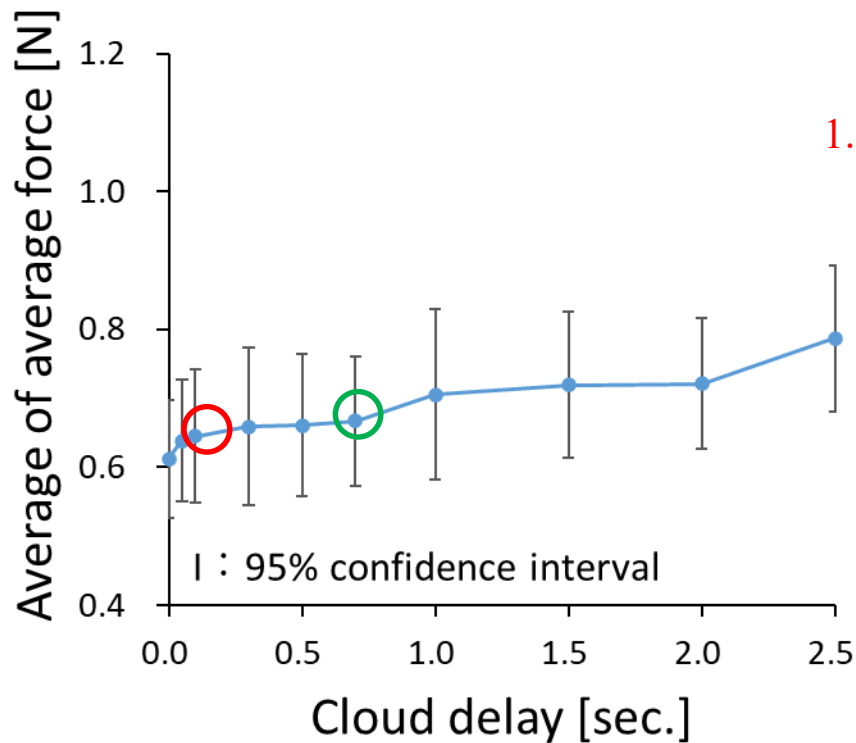
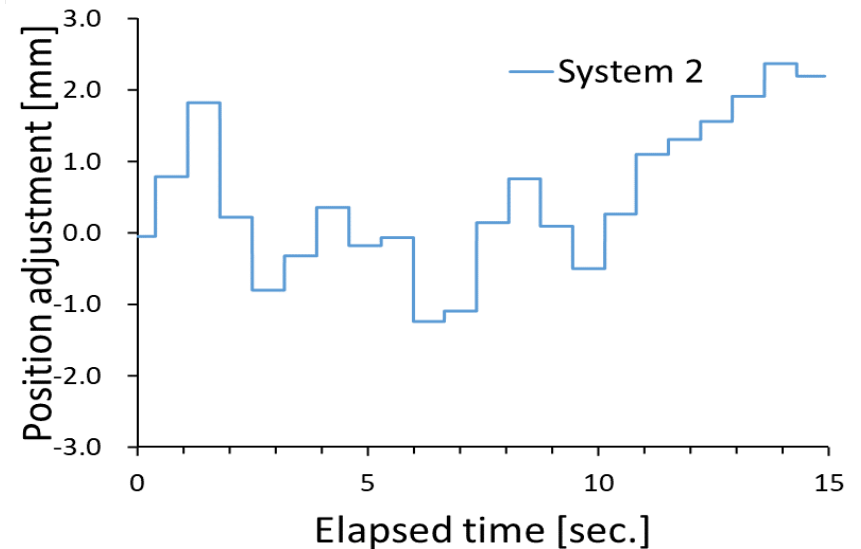**Average of average force**
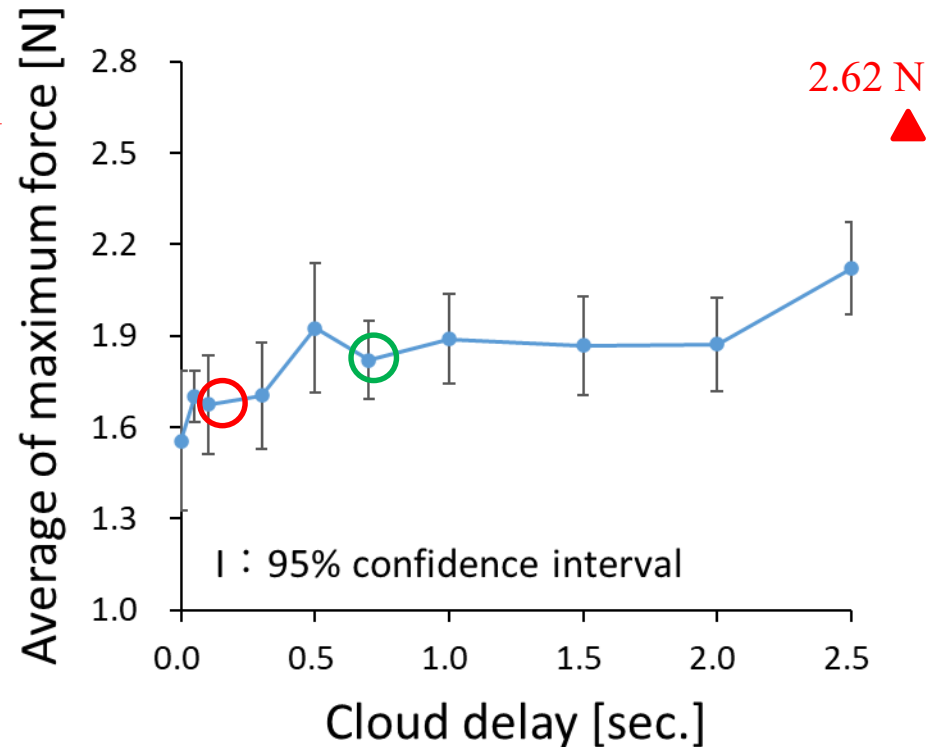
Average of maximum force
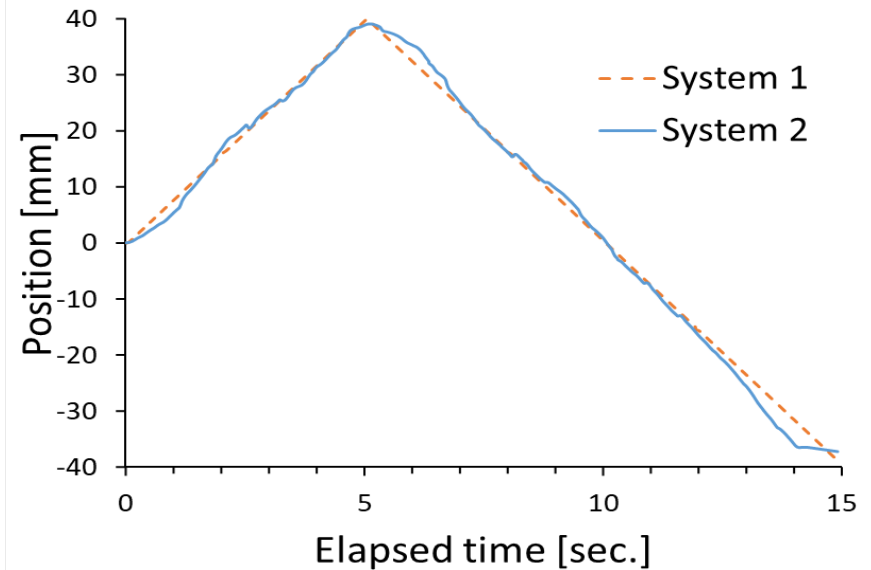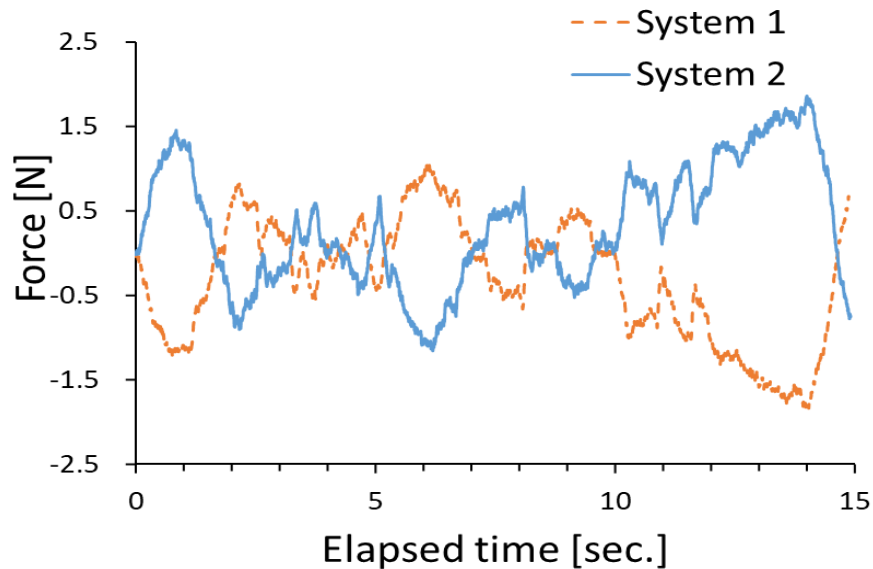
Cloud delay: 100 ms

Experimental Results (3/3)

Cloud delay: 700 ms

Conclusions

➢ **Applied big data, cloud computing, and neural network to the robot position control using force information as QoS control for the remote robot systems with force feedback.**

➢ **Investigated the influence of cloud delay by using the optimum values of the control instead of neural network.**

The force applied to the wooden stick is reduced even if the cloud delay is large.

The application of big data, cloud computing, and AI technologies to the QoS control is effective.

Future Work

➢ **Build an experiment environment using big data, cloud computing, and neural network for the robot position control using force information**

➢ **Investigate effects of neural network for the QoS control by experiment**

➢ **Apply our method to other types of QoS control**