Robot Position Control Using Force Information in Remote Robot Systems: Influence of Network Delay

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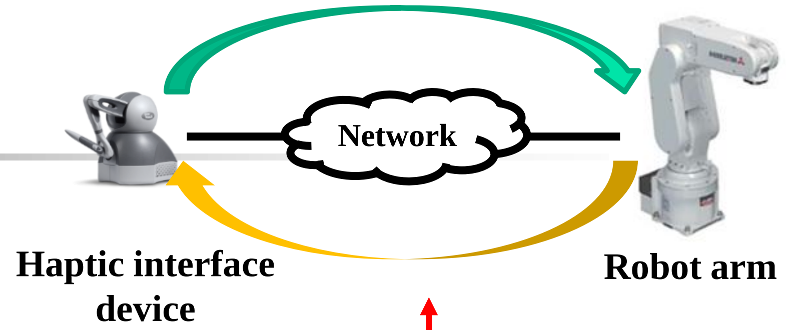
Outline

- Background
- Previous Work
- Purpose
- Remote Robot Systems with Force Feedback
- Robot Position Control Using Force Information
- Experiment Method
- Experimental Results
- Conclusion and Future Work

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 robot arms 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, where 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.

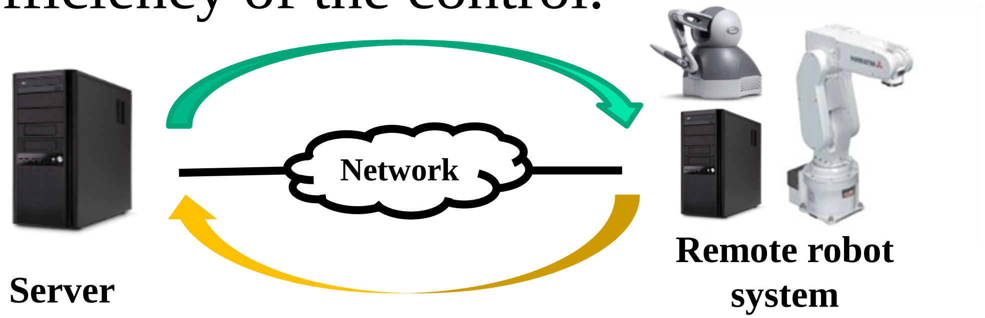
- Applied **robot position control using force information**[*1] to a remote robot system for stable cooperative work (***carrying an object together***).

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

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

Previous Work (2/2)

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



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

Purpose

previous work

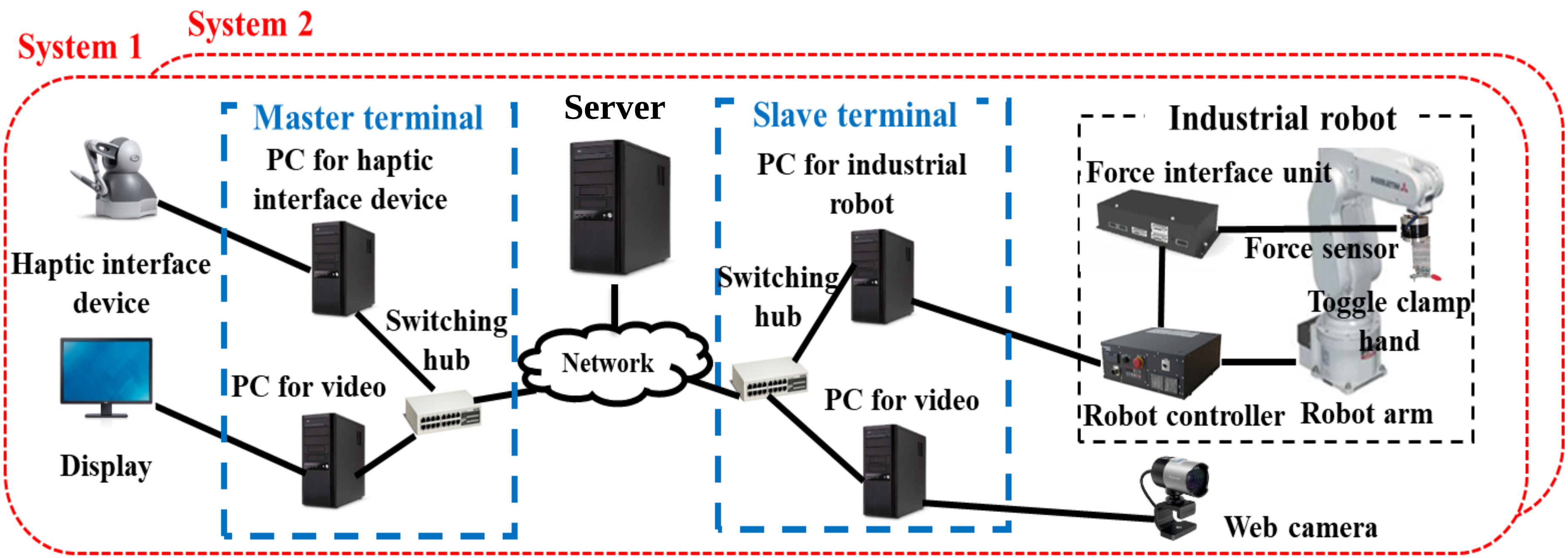
- It is essential to transmit information to the cloud and provide feedback to the remote robot system through a network where QoS is not guaranteed.

➡ The influence of network delay have not been clarified so far.

This work

We investigate the influence of network delay on cooperative work of carrying object between two remote robot systems.

Remote Robot Systems with Force Feedback



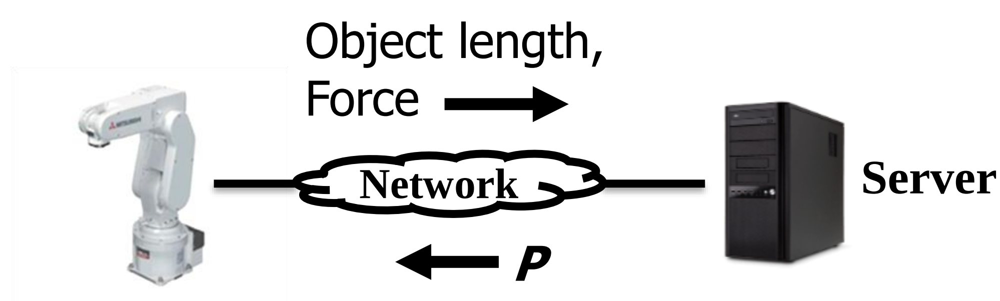
Configuration of two remote robot systems with force feedback

Robot Position Control Using Force Information

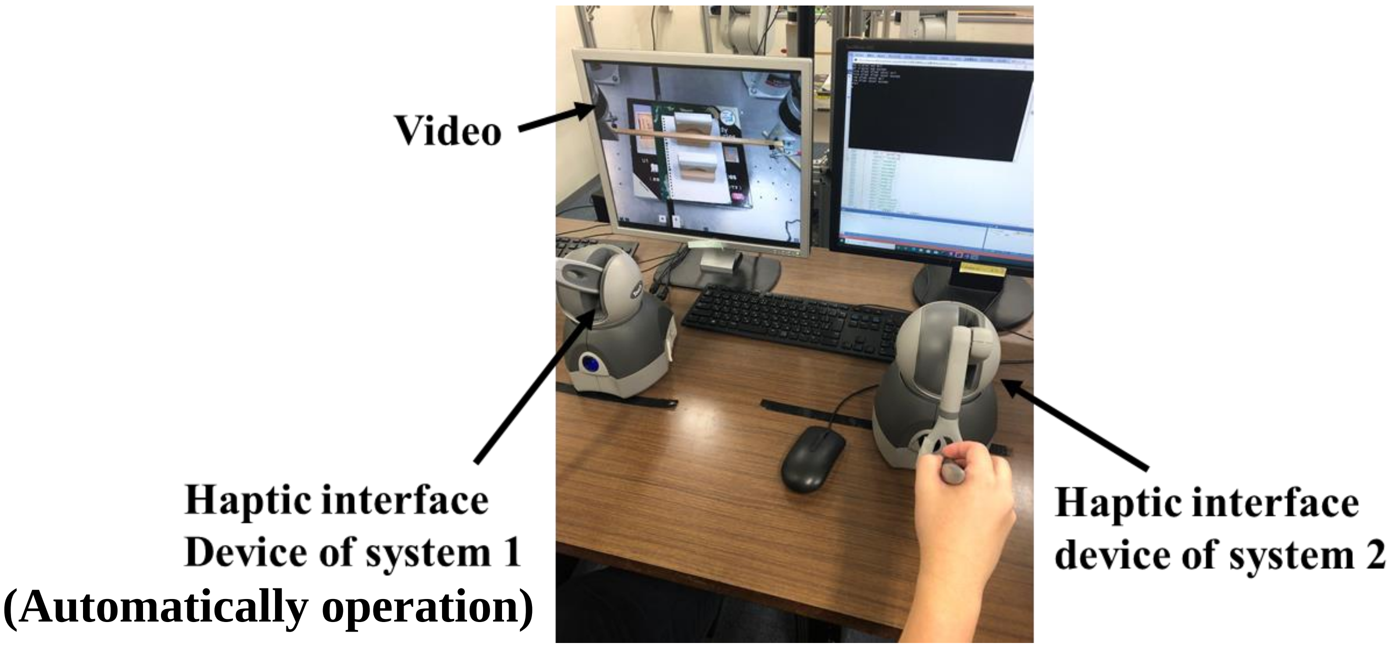
$$\hat{\boldsymbol{S}}_t = \boldsymbol{S}_t + \boldsymbol{P}$$
$$\boldsymbol{P} = a\boldsymbol{F}$$

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

- $\hat{\boldsymbol{S}}_t$: 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
- a : Coefficient (depending on length of the object)



Experiment Method (1/3)



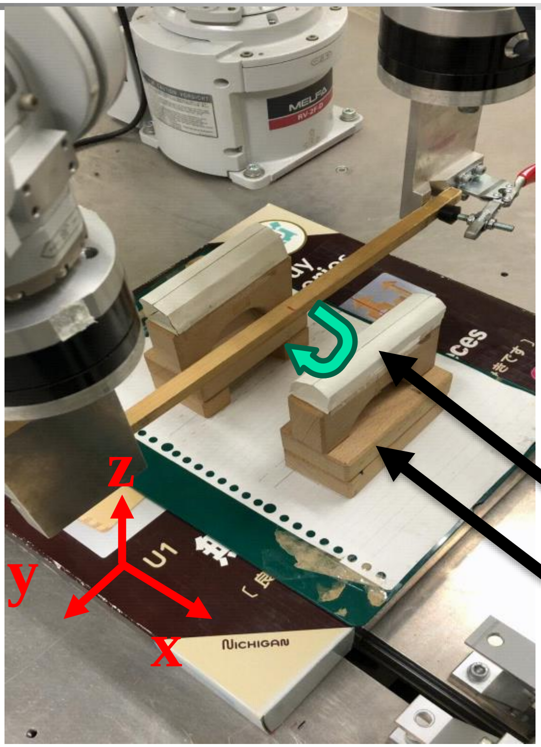
Operation with haptic interface devices

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

Experiment Method (2/3)

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 touch while keeping the robot arms parallel to each other.
- To move the stick at almost the same speed, he/she touched the first paper block at about **6** seconds from the beginning of each work and the second block at about **12** seconds.

Experiment Method (3/3)

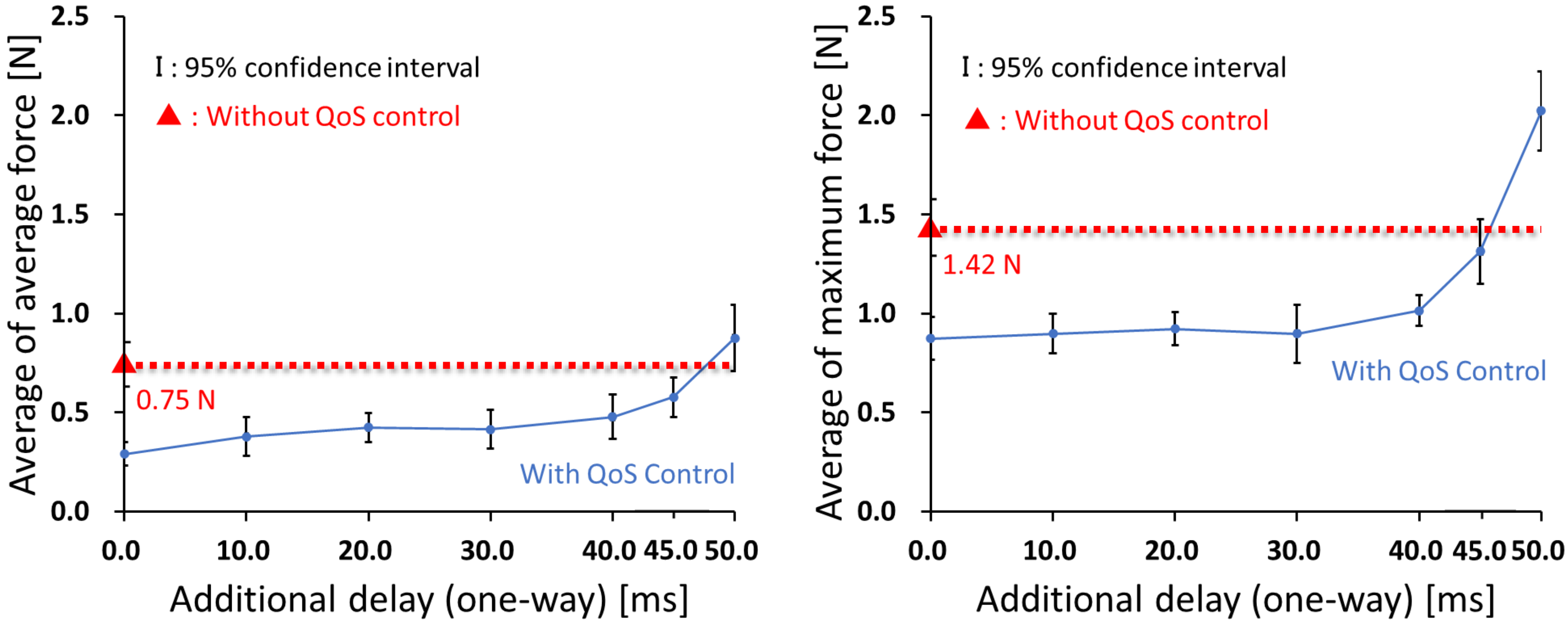
*2 M. Carson*et al.*, ACM SIGCOMM. 33 3, pp. 111-126, July 2003.
*3 S. Ishikawa *et al.*, IEICE Technical Report, CQ2019-34, July 2019.

- 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 [*2]).

- The server calculated **the optimal value**[*3] for position adjustment instead of using a 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)

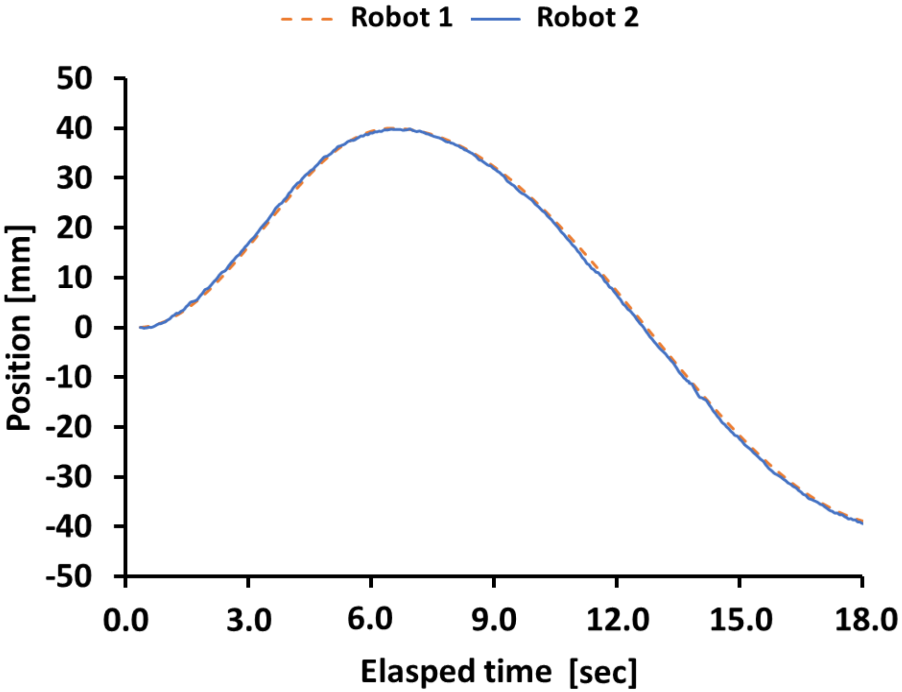


(a) Average of average force (a) Average of maximum force

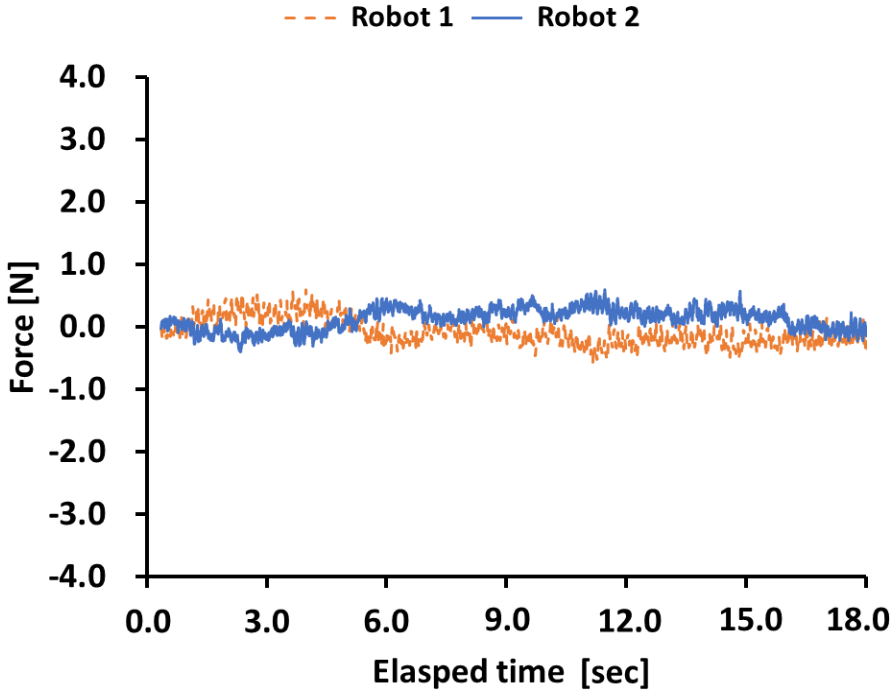
- Both the average of average force and the average of maximum force increase as the additional delay becomes **larger**.
- The force applied to the wooden stick is **reduced** by **robot position control** until the additional delay of **45 ms**

Experimental Results (2/4)

- **With** Control
- Additional Delay: **0 ms**



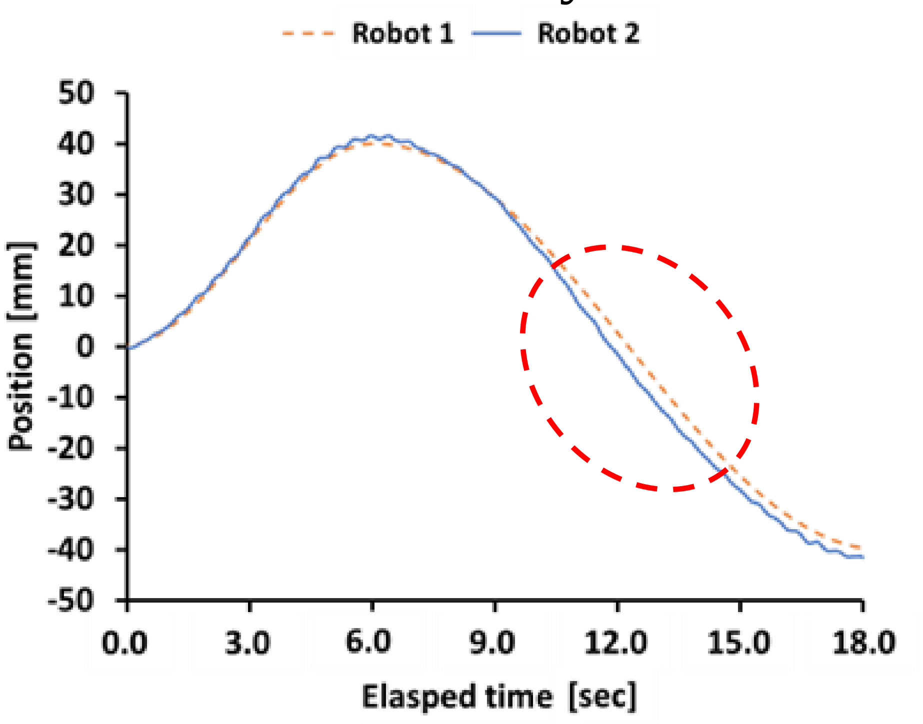
(a) Positon



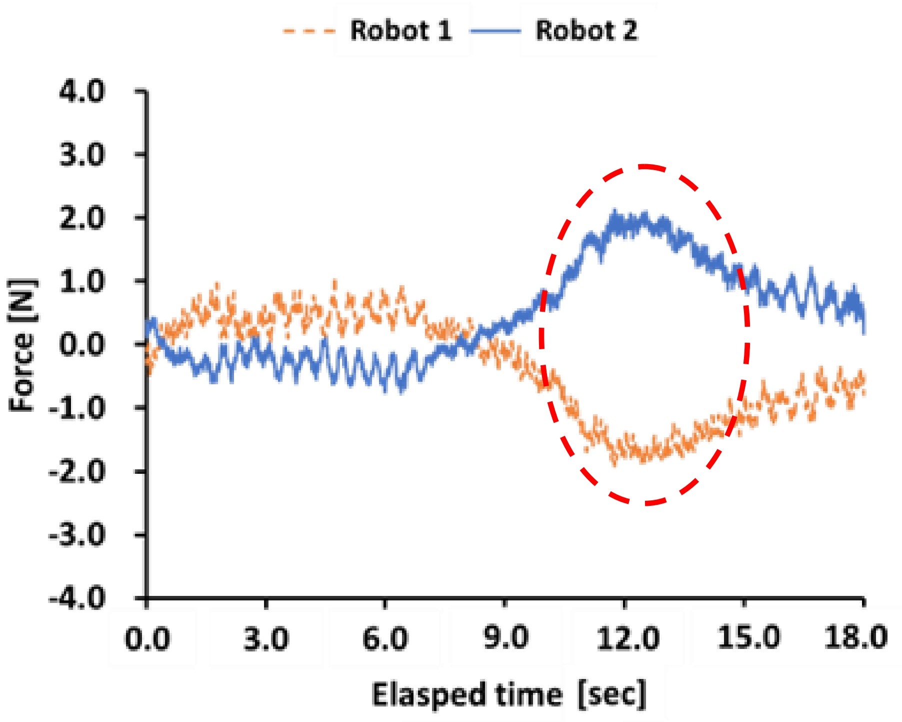
(b) Force

Experimental Results (3/4)

- **With** Control
- Additional Delay: **50 ms**



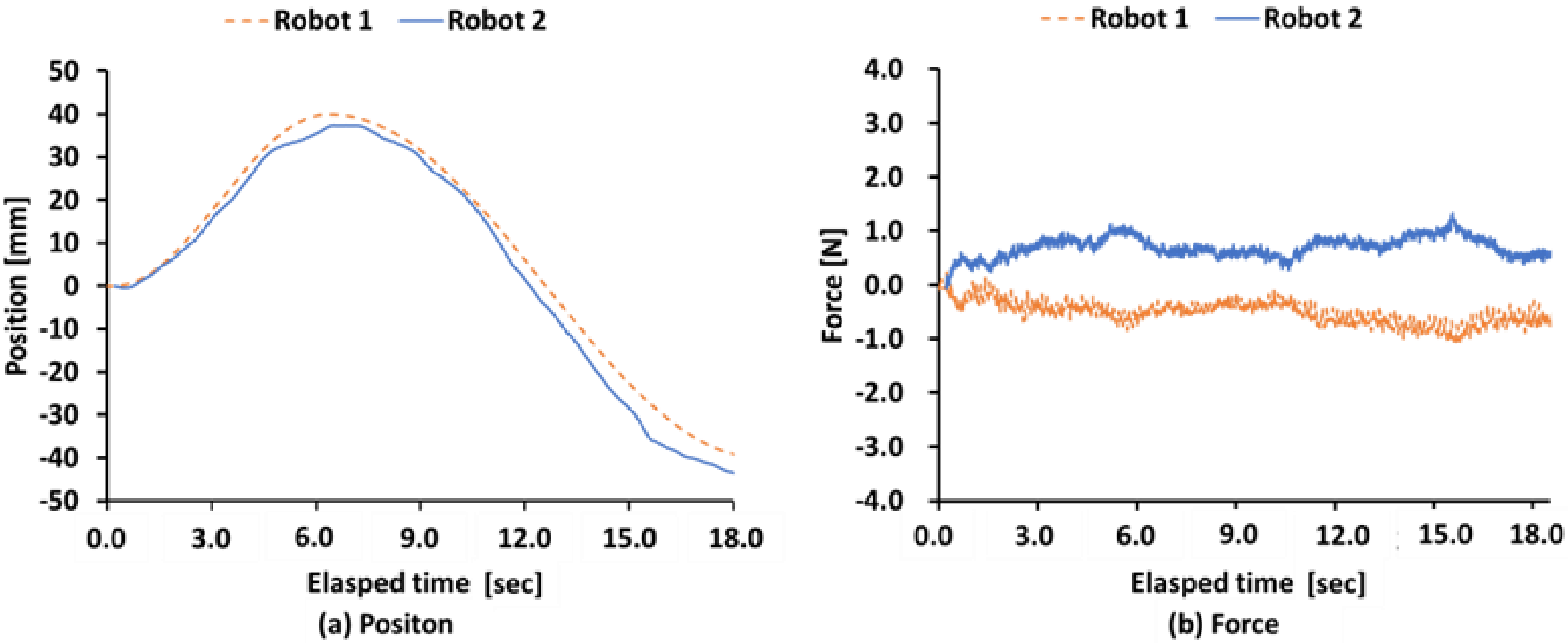
(a) Positon



(b) Force

Experimental Results (4/4)

- **Without** Control
- Additional Delay: 0 ms



(a) Positon (b) Force

Conclusion

- We applied **the robot position control using force information** as QoS control to a remote robot system with force feedback.
- We used **the optimal adjusted value** that obtained from server instead of neural networks and investigated the influence of network delay.

✓ The control is effective when the network delay is less than approximately **50 ms**.

Future Work

- Construct an experiment environment for QoS control using neural networks on a server.
- Validate the effectiveness of the control by experiment.