Effect of Robot Position Control with Force Information for Cooperative Work between Remote Robot Systems

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December 22, 2019, WSCE 2019, Nagoya Institute of Technology, Japan

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Background (1/2)

Remote robot systems with force feedback have actively been studied.

It is possible for users to feel the shape, softness, surface smoothness, and weight of a remote object by using haptic interface device (force feedback).

The efficiency and accuracy of cooperative work are expected to be largely improved.

Background (2/2)

When information about force is transmitted over a network such as the Internet, which does not guarantee QoS (Quality of Service)

Network delay, delay jitter and packet loss

- Degradation of QoE (Quality of Experience)
- Instability phenomena

QoS control and stabilization control

Problem

*1 Y. Ishibashi *et al.*, Proc. ICCAR, Apr. 2019.

Previous Study*1

- The robot position control with force information was proposed for cooperative work (*carrying an object together*).
- The robot position is adjusted to reduce the force applied to the object under the control.

  - ✓ The force applied to the object under the control is smaller than that under no control.
  - ✓ The force applied to the object increases as the network delay becomes larger.
  - ✓ The value of position adjustment depends on the length of the carried object.

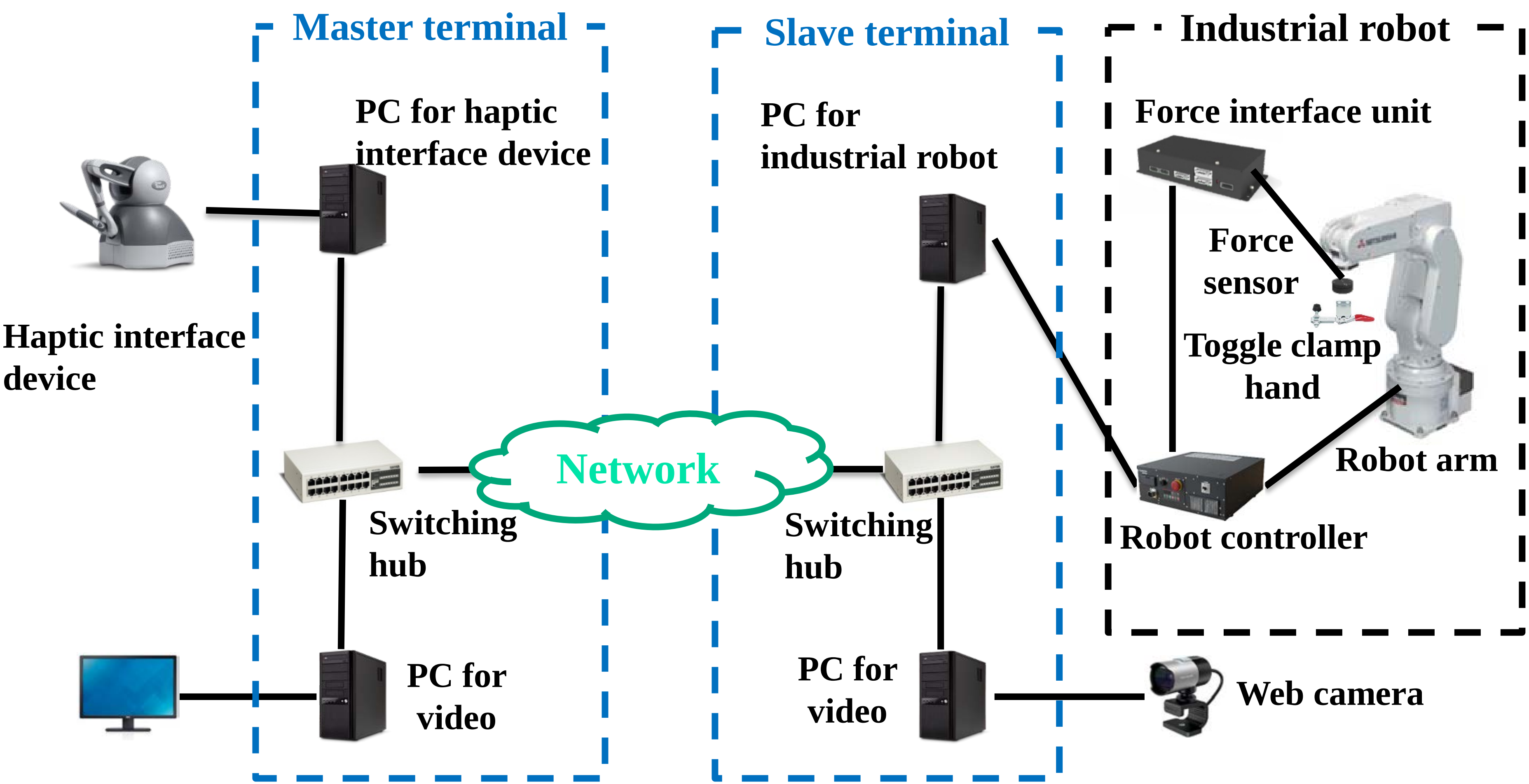
The optimal value has not be clarified.

Purpose

This Study

- **We enhance the robot position control with force information by analyzing the relation between the length of the object and the force applied to the object.**
- **We obtain equations for the optimal value of position adjustment for the cooperative work (*carrying the object together*).**
- **We investigate the influence of network delay on the force applied to the object by experiment.**

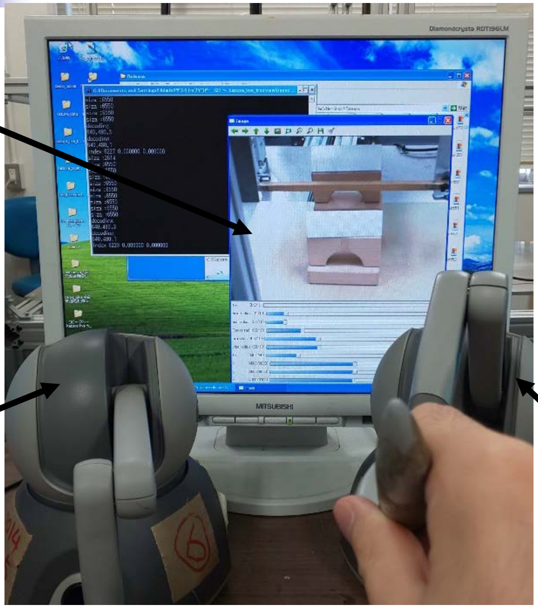
Remote Robot System with Force Feedback



We use the two systems in our experiment.

*2 P. Huang *et al.*, IJCNS, July. 2019

Cooperation between Systems



Master terminal

Slave terminal

- As cooperative work, we handle work in which the two robot arms carry a wooden stick together.
- To avoid instability phenomena (vibrations), we carry out the stabilization control with filter*2 and disable the movement of each robot arm in the left-right direction (y axis) for each system.

Robot Position Control with Force Information[*1]

*1 Y. Ishibashi *et al.*, Proc. ICCAR, Apr. 2019.

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

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

$\widehat{\boldsymbol{S}_t}$: **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** $t(> 0)$

$\boldsymbol{P}$: **Vector of position adjustment**

*3 Q. Qian *et al.*, Proc. ICCC, Dec. 2018.

Equations of Position Adjustment (1/2)

We move the one robot arm by *P*, and measure the force applied to the stick[*3].

Actual length L of wooden stick	Relations between $\boldsymbol{P}$ and $\boldsymbol{F}$
30 cm	$P_x = 2.79 \times 10^{-1} F_x$ $P_z = 3.49 \times 10^{-1} F_z$
45 cm	$P_x = 1.03 F_x$ $P_z = 1.25 F_z$
60 cm	$P_x = 1.73 F_x$ $P_z = 2.39 F_z$

$\boldsymbol{P} = (P_x, P_z)$ **: Movement distance of the robot arm at x and z axes**

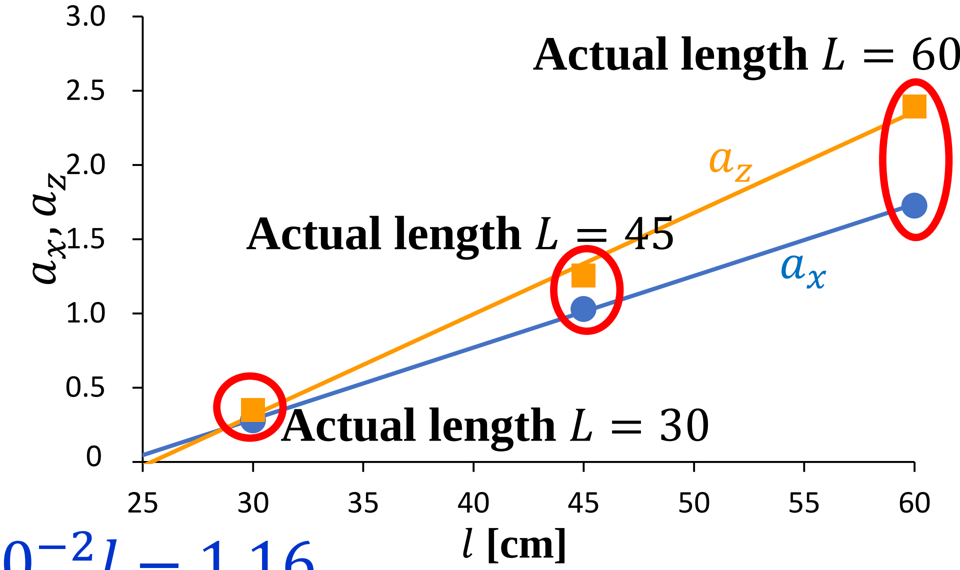
$\boldsymbol{F} = (F_x, F_z)$**: Force vector sensed by force sensor at x and z axes**

Equations of Position Adjustment (2/2)

Denote P_x and P_z as follows:

$$P_x = a_x F_x, P_z = a_z F_z$$

By regression analysis, the relation between $\boldsymbol{A} = (a_x, a_z)$ and actual length L is obtained.



$$a_x = 4.82 \times 10^{-2} l - 1.16$$
$$a_z = 6.82 \times 10^{-2} l - 1.73$$

l : Length of wooden stick

- **By using A, we can obtain the optimal equations (the optimal value of l) between the position and the force for the stick with actual length of L.**
- **Because a_x and a_z are positive, the value of l should be larger than 25 cm.**

The optimal value of l may not be equal to the actual length L.

Experiment Method (1/4)

- **One system (*system 1*) was operated automatically and the other system (*system 2*) was operated manually by a user.**
- **The robot arm of system 1 was moved at a constant speed.**
- **The robot arm of system 2 was operated to follow that of system 1.**

Haptic interface devices

Robot arms

Experiment Method (2/4)

- **The robot position control with force information was carried out in system 2 which was operated manually by a user.**

- **The constant delay (*additional delay*) was added to each packet transferred between the master and slave terminals of each system by using a network emulator.**
  - ✓ **The additional delay : 0 ms, 200 ms, 400 ms**

- **Used wooden sticks :** $L = 30$ **cm**

  $L = 45$ **cm**

  $L = 60$ **cm**

Experiment Method (3/4)

- **We investigated the minimum value of l (l_{min}) when instability phenomena occurred.**

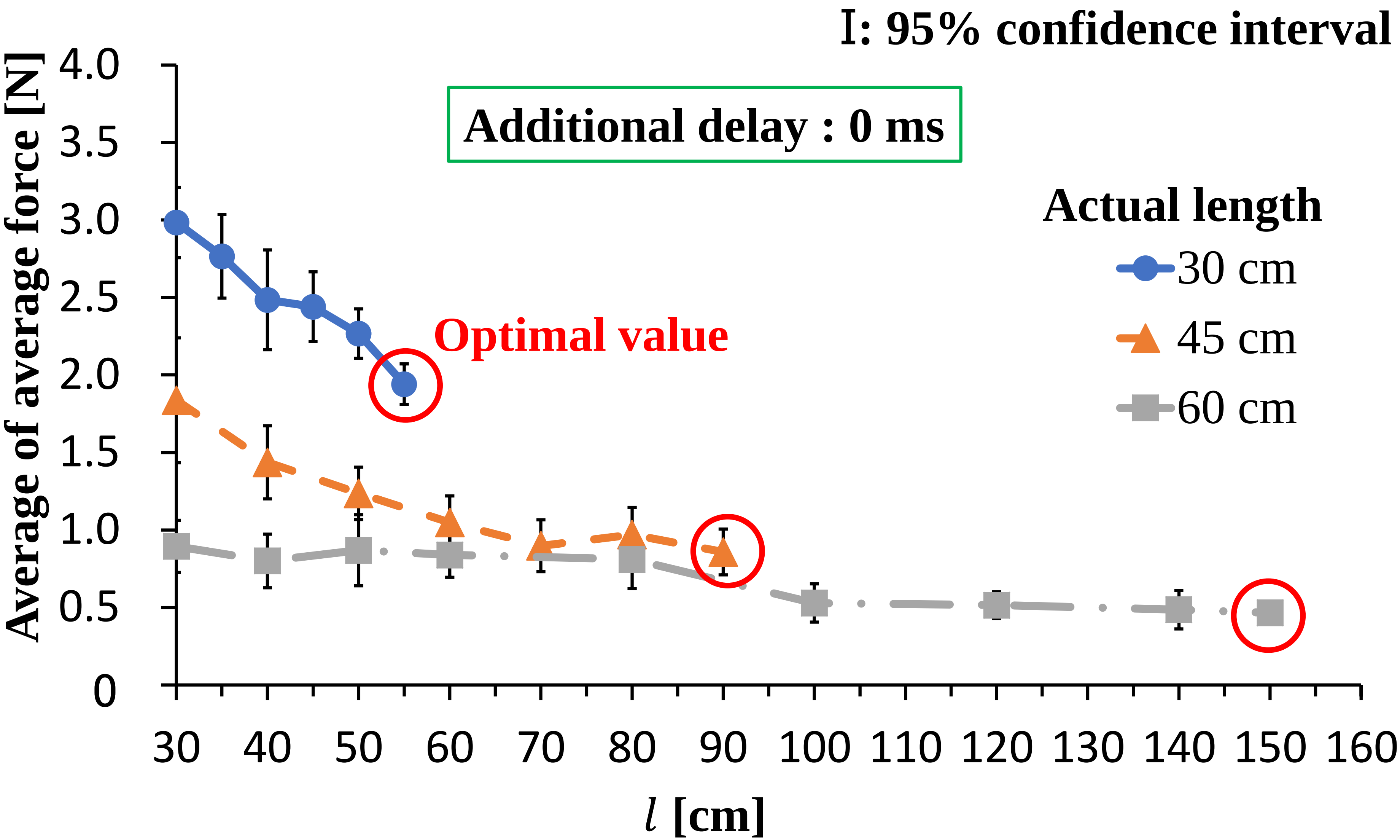
Actual length of stick L	l_{min} when instability phenomena occurred
30 cm	60 cm
45 cm	100 cm
60 cm	160 cm

- **The value of l was selected from among values larger than or equal 30 cm and less than l_{min}.**

Experiment Method (4/4)

- **For each stick, the combinations of the additional delay and the value of** l **were changed in random order, and the work was performed 10 times.**
- **We measured the force applied to the stick during the work and obtained the average of the 10 times (called *the average of average force*).**

Experimental Results



Conclusion and Future Study

Conclusion

- We investigated the optimal value of position adjustment in the robot position control with force information for cooperative work between the remote robot systems.
- One system was operated automatically and the other system which carried out the robot position control with force information was operated manually by a user.

⇒ The optimal value depends on the actual length, and hardly depends on the network delay.

Future Study

Apply the robot position control with force information to both systems