Robot Position Control with Force Information in Cooperation between Remote Robot Systems

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Outline

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- **Robot Position Control with Force Information**
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Background

- By using force information in addition to conventional audiovisual information, it is possible to improve efficiency of remote robot control.
- The operation includes the transmission of commands (e.g., position information) to robot and force information to humans (i.e., Force Feedback).

Transmission of commands and force information in QoS (Quality of Service) non-guaranteed network

Network delay, delay jitter, and packet loss

Degradation of QoE (Quality of Experience) and Stability (e.g., vibrations)

QoS Control and Stabilization Control

Problem

Previous Work

By carrying out stabilization control with filter[1] in remote robot systems with force feedback, each system can be stable. However, as the network delay increases, the absolute value of force becomes larger[2].

By taking advantage of the relation between the average force and the moved distance obtained in [3], we may be able to reduce the force and improve the efficiency of cooperative work.

[1] T. Miyoshi and K. Terashima, "A stabilizing method for non-passive force-position teleoperating system," in Proc. 35th SICE Symposium on Control Theory, vol. 35, pp. 127-130, Sep. 2006.
[2] E. Taguchi, Y. Ishibashi, P. Huang, Y. Tateiwa, and T. Miyoshi, "Comparison of stabilization control in cooperation between remote robot systems with force feedback," in Prof. The 11th International Conference on Future Computer and Communication (ICFCC), Feb. 2019.
[3] D. Osada, Y. Ishibashi, P. Huang, and Y. Tateiwa, "Human perception of force direction in remote robot system with haptics," (in Japanese), IEICE Technical Report, CQ2018-31, July 2018.

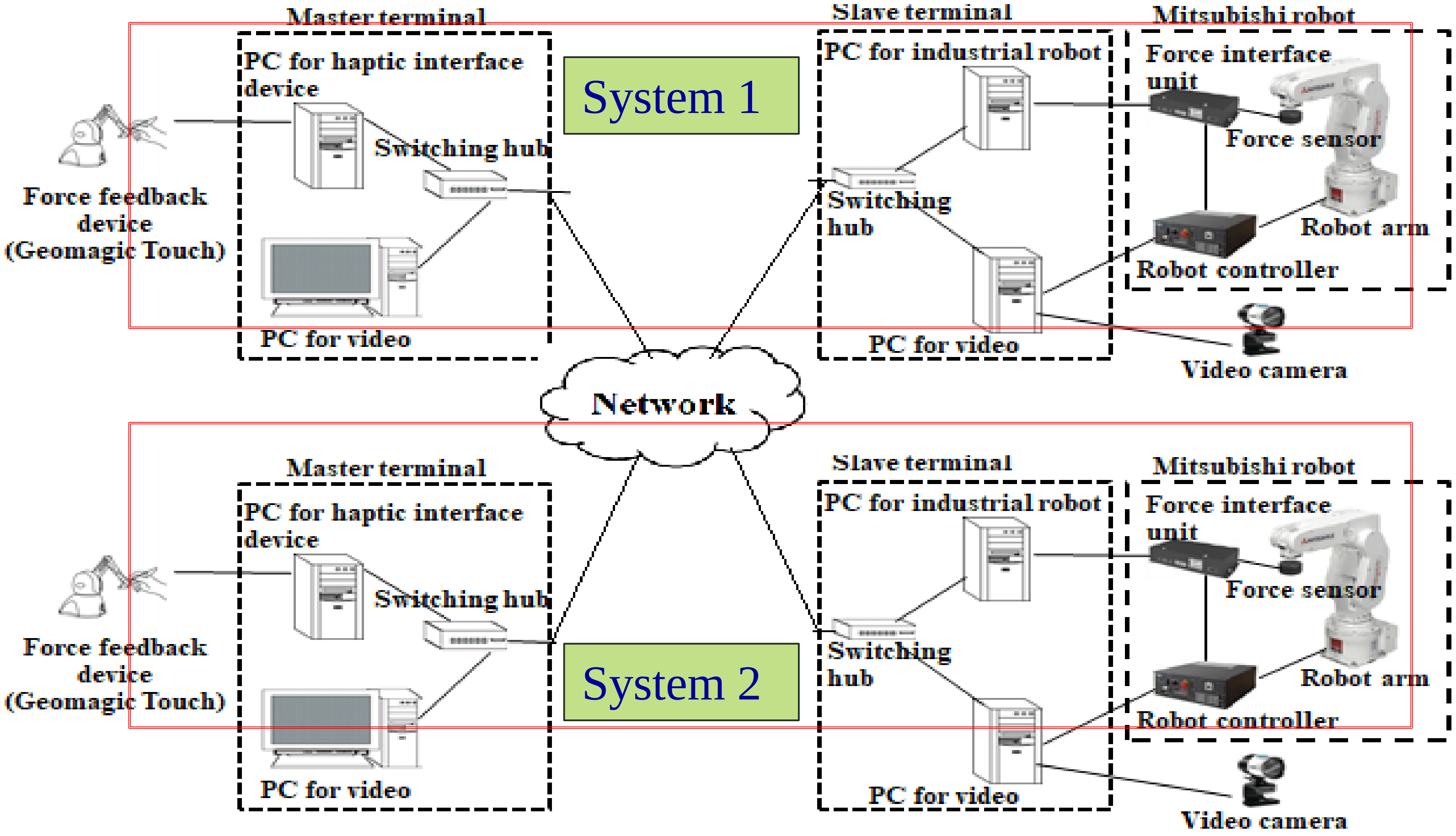
Purpose

This Work

- **We propose robot position control which moves the robot arm in the direction so as to reduce the force for the cooperative work in [2].**
- **We also demonstrate the effectiveness of the control by experiment.**

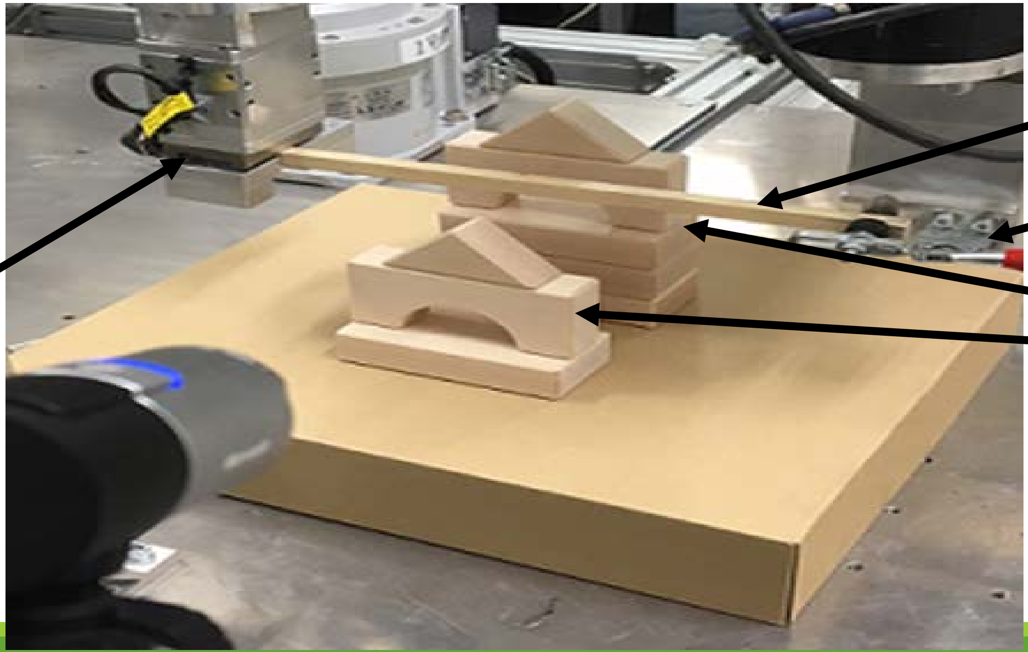
[2] E. Taguchi, Y. Ishibashi, P. Huang, Y. Tateiwa, and T. Miyoshi, "Comparison of stabilization control in cooperation between remote robot systems with force feedback," in Prof. The 11th International Conference on Future Computer and Communication (ICFCC), Feb. 2019.

Remote Robot Systems with Force Feedback



Carrying Object Together

- As one of cooperation works, a user moves a wooden stick with length 0f 30 cm together by the two industrial robot arms operated with his/her both hands.
- He/she pushes and drops the uppermost block of the piled building blocks (front and back) by moving the robot arm together with the force feedback devices while watching video.



Wooden Stick

Fixed by grip

Arrangement of wooden building blocks

Grasped by electric hand

Calculation of Position and Force

Robot position

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

$\boldsymbol{S}_t$: **Position vector of robot at time** t (>0)

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

$\boldsymbol{V}_t$: **Velocity vector of robot at time** t

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

Force outputted at mater terminal

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

$\boldsymbol{F}_t^{(\mathrm{m})}$: **Reaction force outputted at master terminal at time** t (>0)

$\boldsymbol{F}_t^{(\mathrm{s})}$: **Force received by master terminal from slave terminal at time** t

K_{scale} : **Scale multiplied to** $\boldsymbol{F}_t^{(\mathrm{s})}$ $(K_{\mathrm{scale}} > 0)$

Robot Position Control with Force Information

The relation between the moved distance of robot hand and average force was measured[3]. These equations are for the stick with length of 30 cm.

$$P_x = 0.279452F_x - 0.003440$$
$$P_y = 0.112288F_y - 0.000510$$
$$P_z = 0.348769F_z + 0.007467$$

$P_x,\ P_y,\ P_z$: Positions of robot at $x, y,$ and z axes

$F_x,\ F_y,\ F_z$: Force sensed by force sensor at $x, y,$ and z axes

By adding the position vector $\boldsymbol{P} = (P_x,\ P_y,\ P_z)$ to the position vector of robot $\boldsymbol{S}_t$ (i.e., $\boldsymbol{S}_t + \boldsymbol{P}$), we suppress increase of the reaction force.

[3] D. Osada, Y. Ishibashi, P. Huang, and Y. Tateiwa, "Human perception of force direction in remote robot system with haptics," IEICE Technical Report, CQ2018-31, July 2018.

Demo Video – Carrying object together

Working space mapping rate
(force feedback device：robot = 2 : 1)

Experiment Method

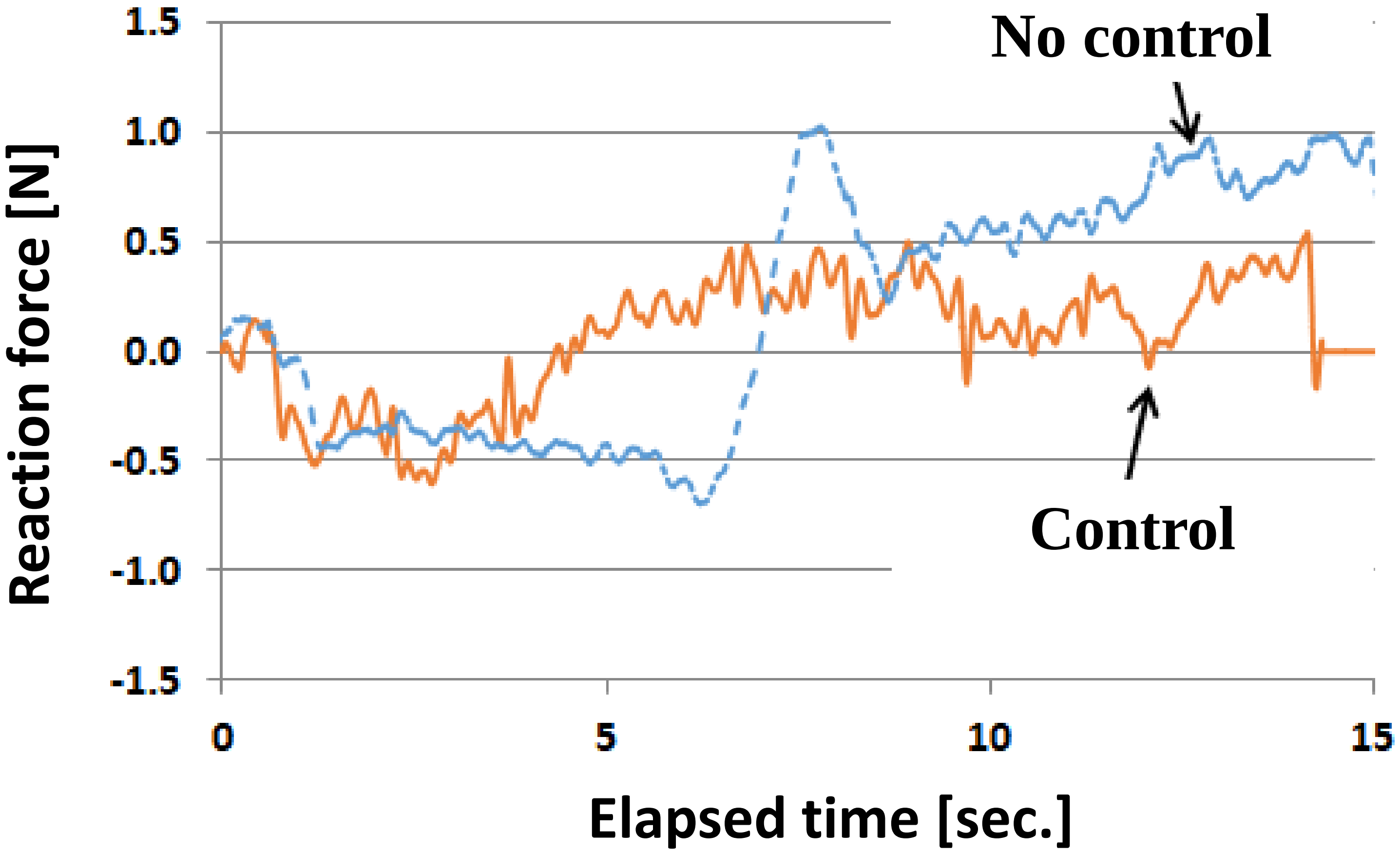
- **To investigate the influence of the network delay, we generated a constant delay (called the *additional delay*) for each packet transmitted between the master and slave terminals by a network emulator.**

- **To ensure more stable operation, we disabled the movement of each robot arm in the left and right direction.**

- **We measured the reaction force outputted by the haptic interface device in the following two case: In one case, the robot position control with force information was performed (called *Control*), and in the other case, the control was not exerted (*No control*).**

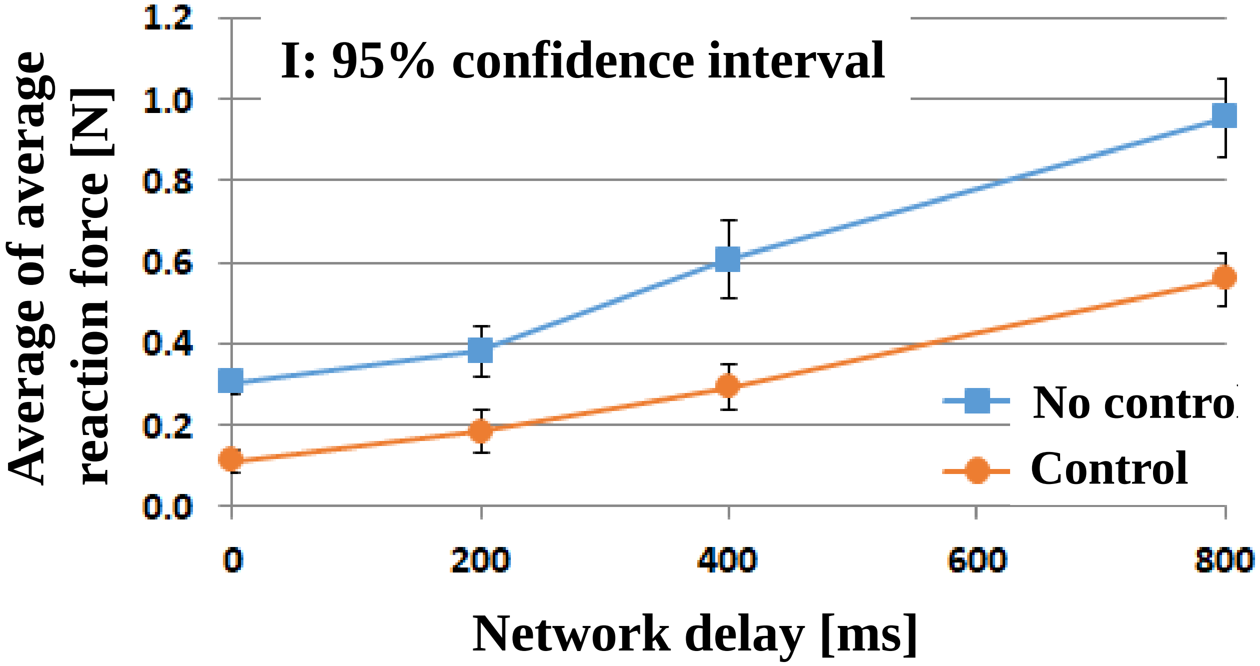
Experiment Results (1/2)

Network delay: 400 ms

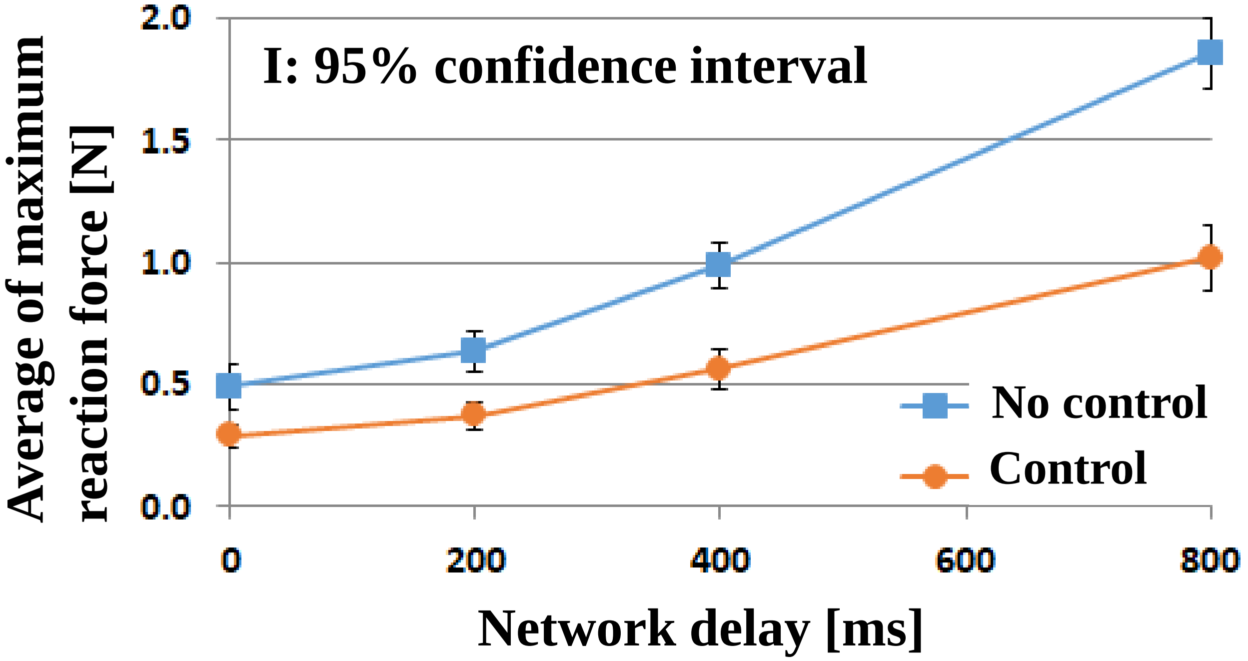


Robot position control with force information makes the absolute reaction force smaller.

Experiment Results (2/2)



Equation of 30 cm



Equation of 60 cm

Average reaction force: ***Time average of absolute reaction force measured during 15 seconds***

Average of average reaction force: ***Mean of 10-time average reaction force***

Equations for Stick with Length of 60 cm

$$P_x = 1.727460F_x - 0.018130$$
$$P_y = 0.130987F_y - 0.002076$$
$$P_z = 2.394680F_z + 0.011130$$

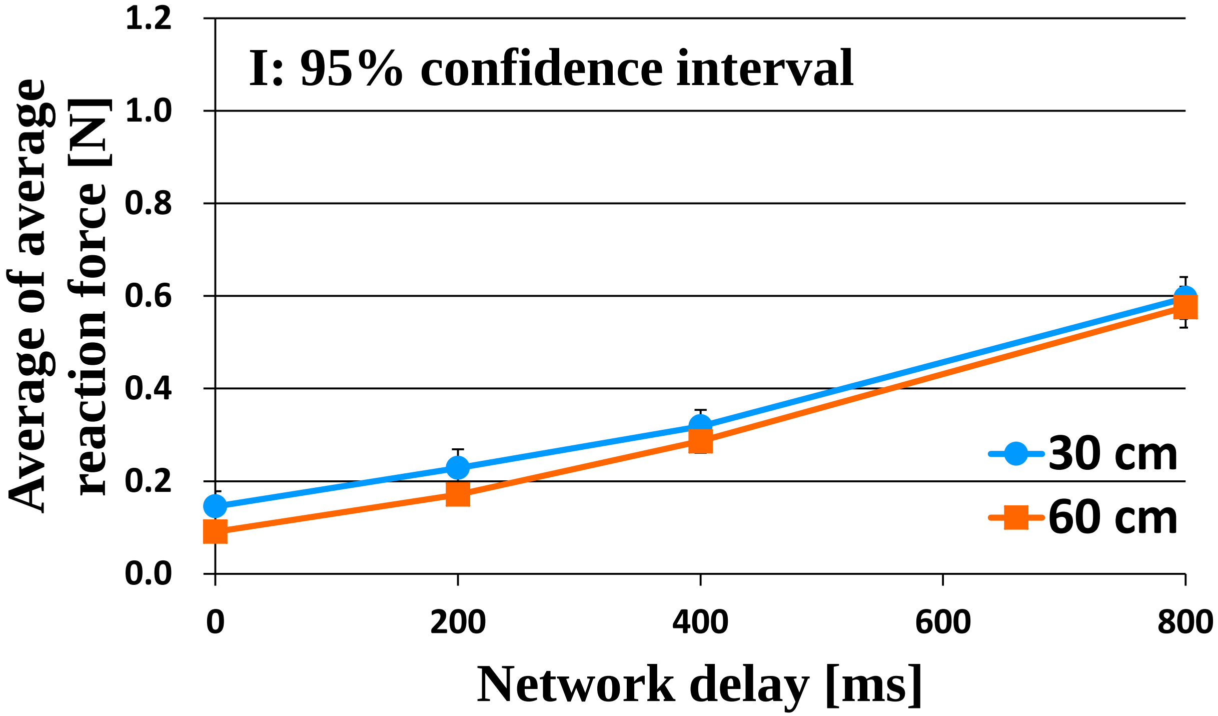
$P_x,\ P_y,\ P_z$: Positions of robot at $x, y,$ and z axes

$F_x,\ F_y,\ F_z$: Force sensed by force sensor at $x, y,$ and z axes

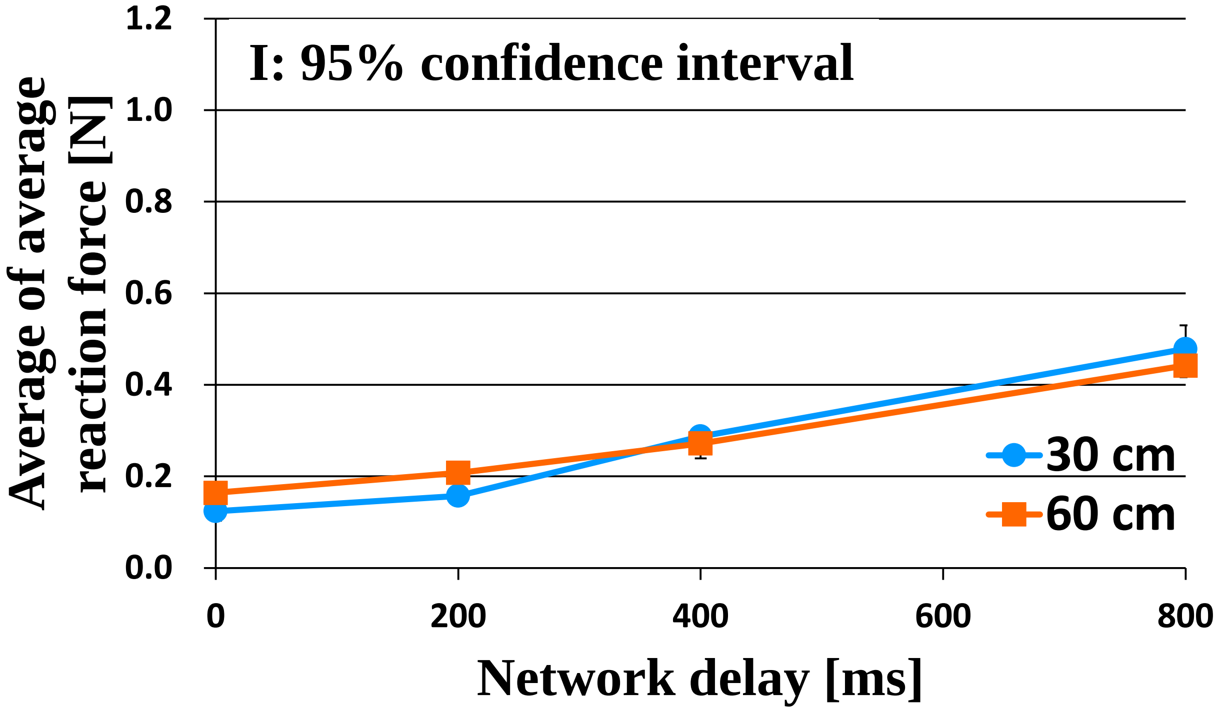
Equations of 30 cm

$$P_x = 0.279452F_x - 0.003440$$
$$P_y = 0.112288F_y - 0.000510$$
$$P_z = 0.348769F_z + 0.007467$$

Comparison between Equations of 30 cm and 60 cm (1/2)



Equation of 30 cm

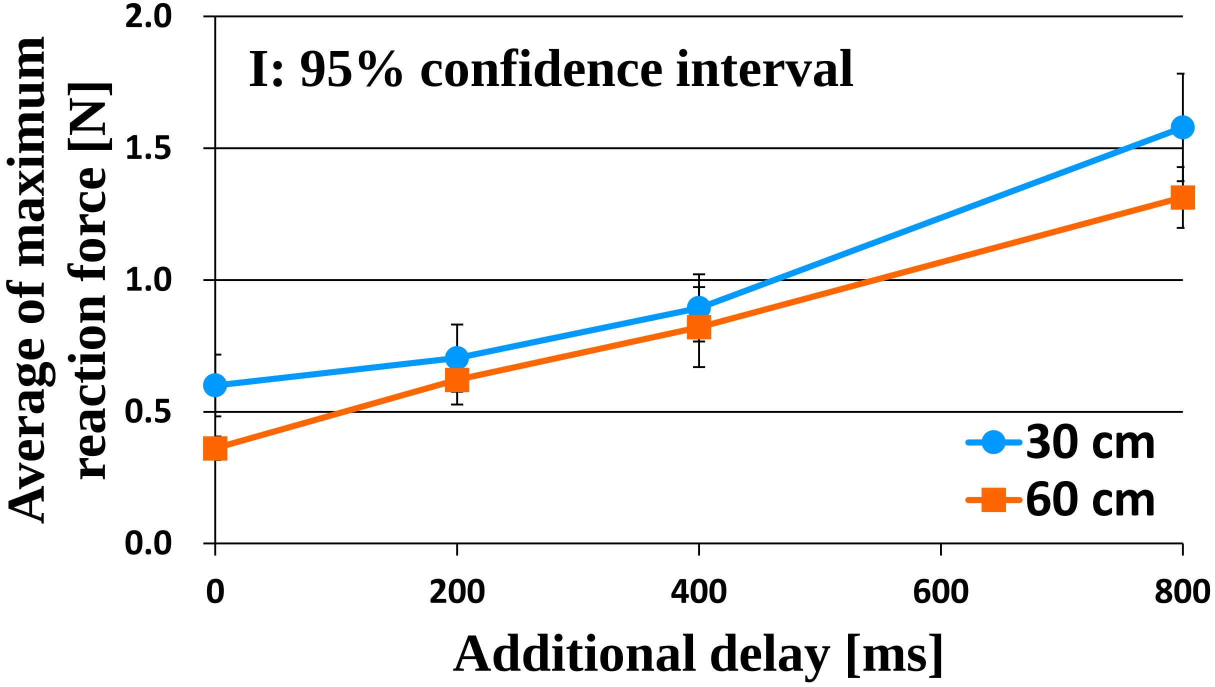


Equation of 60 cm

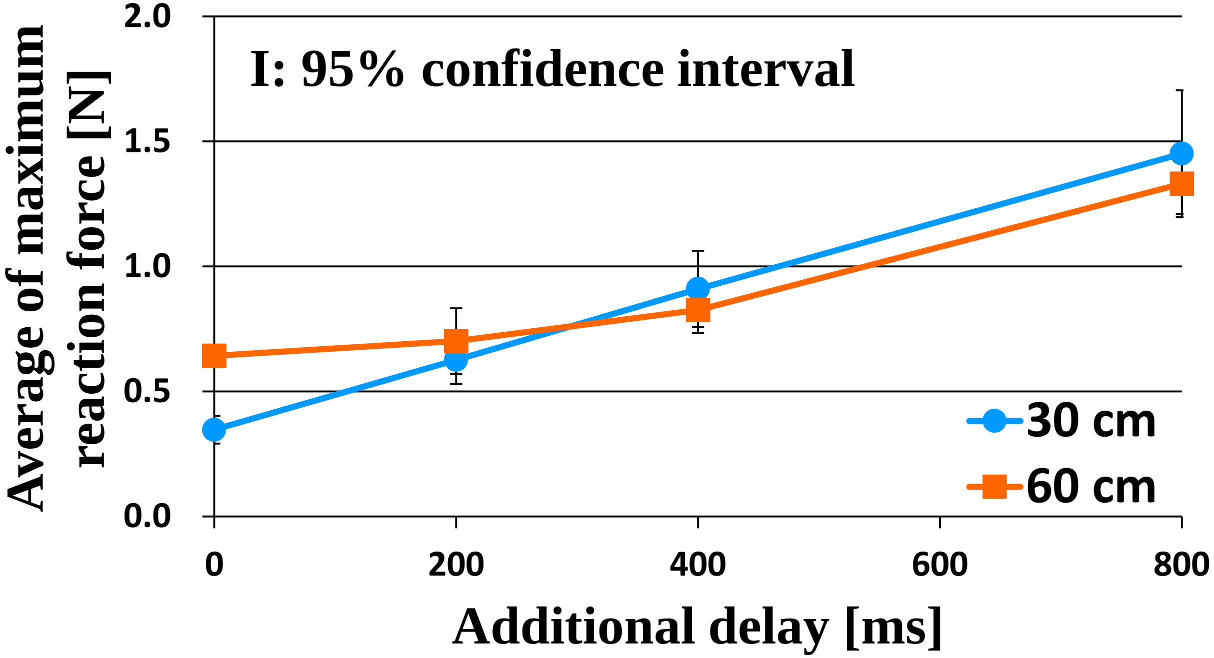
Average reaction force: ***Time average of absolute reaction force measured during 15 seconds***

Average of average reaction force: ***Mean of 10-time average reaction force***

Comparison between Equations of 30 cm and 60 cm (2/2)



Equation of 30 cm



Equation of 60 cm

Maximum reaction force: ***Maximum value of reaction force measured during about 15 seconds***
Average of maximum reaction force: ***Mean of 10-time maximum reaction force***

Conclusions

- We proposed the robot position control with force information for cooperative work between remote robot systems with force feedback.
- We investigated the effectiveness of the control by experiment.

- The absolute value of reaction force of Control is smaller than that of No control.
- There is no large difference between equations of 30 cm and 60 cm.

Future Work

- **Two users perform the work in which each user operates a haptic device with one hand.**

- **We will also find the optimum equations from the network delay and force sensed by the force sensor.**