Remote Robot Operation by Two Users with Force Feedback
ーComparison with One User Operationー

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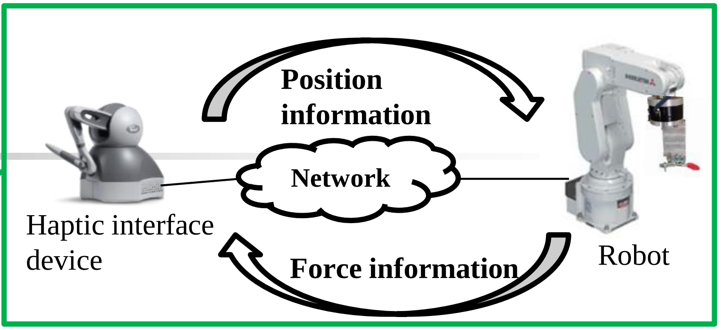
Background (1/3)



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 are expected to be improved largely.

Background (2/3)

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

Network delay, delay jitter and packet loss

QoE (Quality of Experience) deteriorated

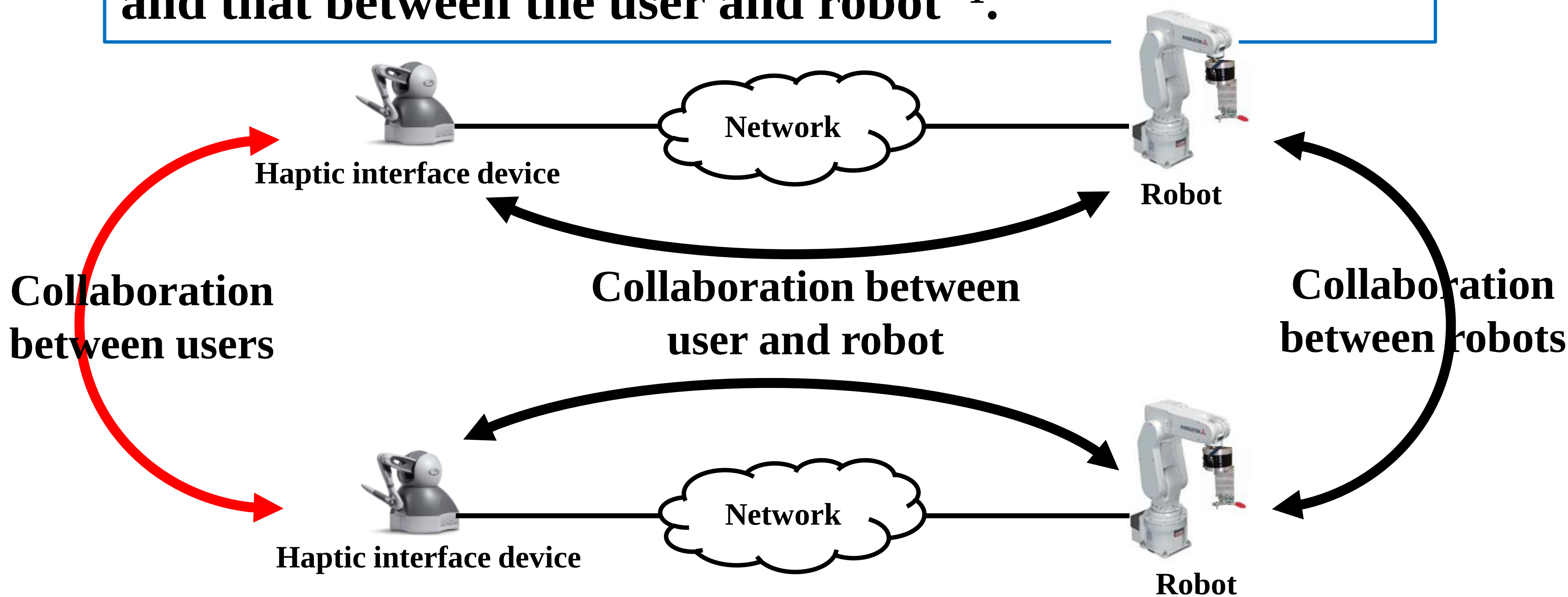
Instability phenomena occur

QoS control + Stabilization control

Background (3/3)

*1 R. Ye *et al.*, ICCCI, July. 2022.

In cooperative work between the systems, effective collaboration between the users (i.e., the haptic interface devices) is required as well as that between the robots and that between the user and robot [*1].



Previous Work (1/3)

*2 T. Hagiwara *et al*., iScience, Dec. 2020.

In virtual environments, there are several papers in which collaboration by multiple users can be superior to that by a single user.

- **Conducted an experiment in which one or two users operate an avatar so that the avatar can touch an object in a 3-D virtual space.**[*2]

The avatar is operated by the one user's movement or by averaging the movements of the two users.

→ **The operation by the two users outperforms that by the one user.**

Previous Work (2/3)

*3 P. Huang *et al.*, ACE, Oct. 2009.

- **By QoE assessment, they illustrated that MOS (Mean Opinion Score) in case 1 is the highest among the three cases.**

They made a comparison among three cases of collaborative play.

Case 1: Two users pile up the blocks by holding them together.
Case 2: They pile up the blocks alternately by holding them separately.
Case 3: One of the two users finds a block piled up next, carries the block to hand it to the other user, who receives it and then piles it up.

Previous Work (3/3)

We can expect that the same kinds of effects (i.e., collaboration by two users may be superior to that by a single user) in virtual environments are obtained in real environments such as remote robot systems with force feedback.

Such a kind of effects has not been examined so far.

Purpose

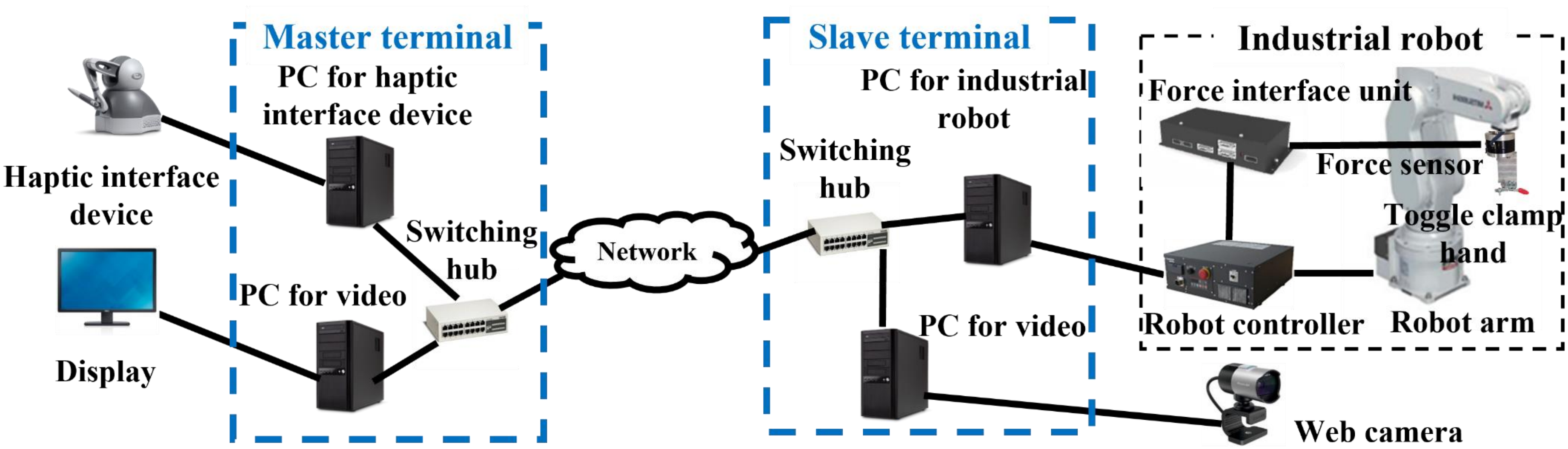
This work

- **Deal with two cases in which an object is carried together by two remote robot systems with force feedback and make a comparison between them.**

- **In one case, one user operates a robot (called the one user operation).**

- **In the other case, two users operate a robot (called the two users operation).**

Remote Robot System with Force Feedback



System configuration of one user operation

Calculation of Force

*4 S. Ishikawa *et al*., IJCNS, pp. 1-13, Mar. 2021.

Calculation of Force in one user operation

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

- $\boldsymbol{F}_t^{(\mathrm{m})}$ **: Force outputted at master terminal at time *t* (*t* ≥ 1)**
- $\boldsymbol{F}_t^{(\mathrm{s})}$ **: Force received from slave terminal at time *t***
- $K_{\mathrm{scale}}^{(\mathrm{F})}$ **: Mapping scale about force between industrial robot and haptic interface device** ($K_{\mathrm{scale}}^{(\mathrm{F})} = 0.33$ *4)

Calculation of Position

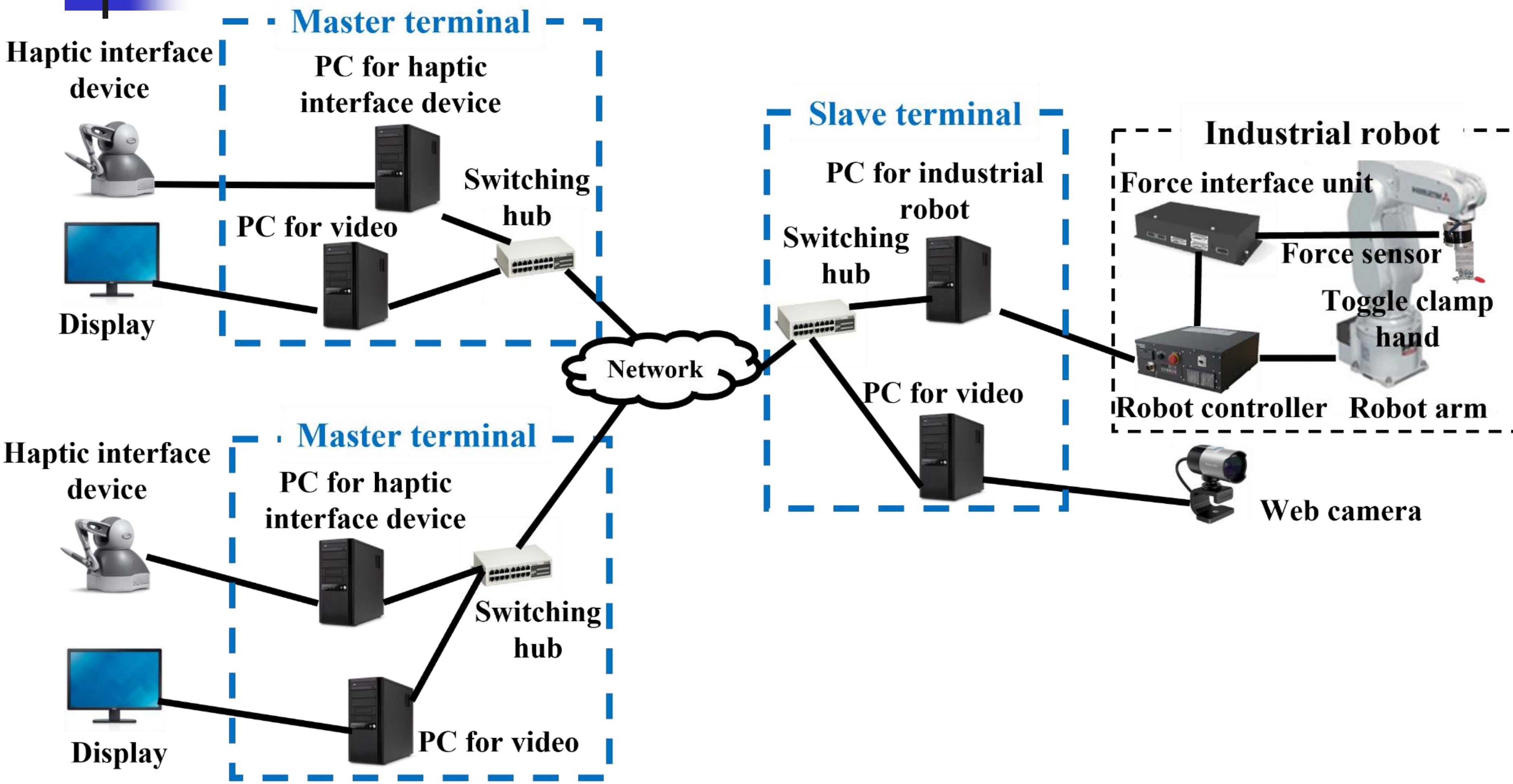
*4 S. Ishikawa *et al*., IJCNS, pp. 1-13, Mar. 2021.

Calculation of Position in one user operation

$$\boldsymbol{S}_t = K_{\mathrm{scale}}^{(\mathrm{P})} \boldsymbol{M}_{t-1} + \boldsymbol{V}_{t-1}$$

- $\boldsymbol{S}_t$ **: Position vector of industrial robot at time *t* (*t* ≥ 1)**
- $\boldsymbol{M}_t$ **: Position vector of haptic interface device at time *t***
- $\boldsymbol{V}_t$**: Moving velocity of industrial robot at time *t***
- $K_{\mathrm{scale}}^{(\mathrm{P})}$ **: Mapping scale about position between industrial robot and haptic interface device** ($K_{\mathrm{scale}}^{(\mathrm{P})} = 0.5$ *4)

Two Users Operation (1/2)



System configuration of two users operation

Two Users Operation (2/2)

Calculation of Force in two users operation

$$\boldsymbol{F}_t^{(\mathrm{m}_1)} = \boldsymbol{F}_t^{(\mathrm{m}_2)} = K_{\mathrm{scale}}^{(\mathrm{F})}\ \boldsymbol{F}_{t-1}^{(\mathrm{s})}$$

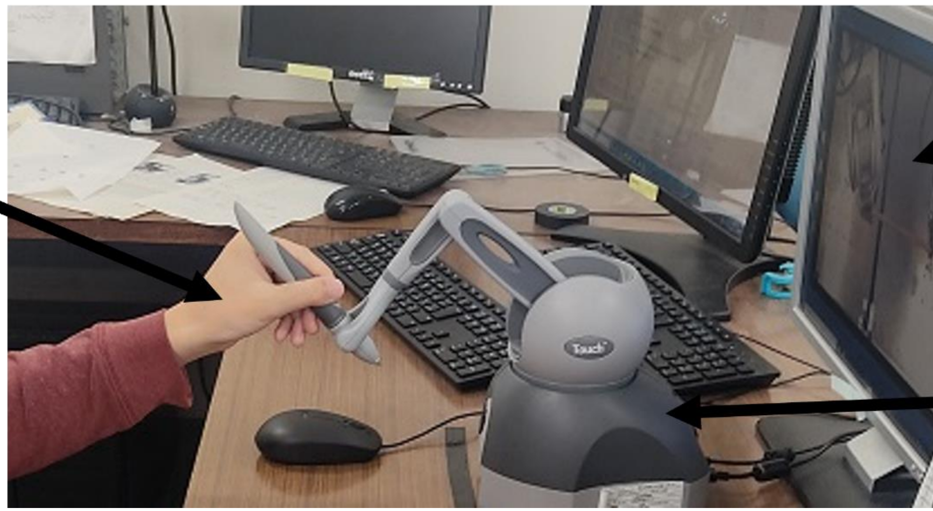
- $\boldsymbol{F}_t^{(\mathrm{m}_i)}$ **: Force outputted at master terminal *i* (*i* = 1 or 2) at time *t* (*t* ≥ 1)**

Calculation of Position in two users operation

$$\boldsymbol{S}_t = K_{\mathrm{scale}}^{(\mathrm{P})}\ \left\{\left(\boldsymbol{M}_{t-1}^{(\mathrm{m}_1)} + \boldsymbol{M}_{t-1}^{(\mathrm{m}_2)}\right)/2\right\} + \boldsymbol{V}_{t-1}$$

- $\boldsymbol{M}_t^{(\mathrm{m}_i)}$**: Position vector of haptic interface device *i* (*i* = 1 or 2) at time *t* (*t* ≥ 1)**

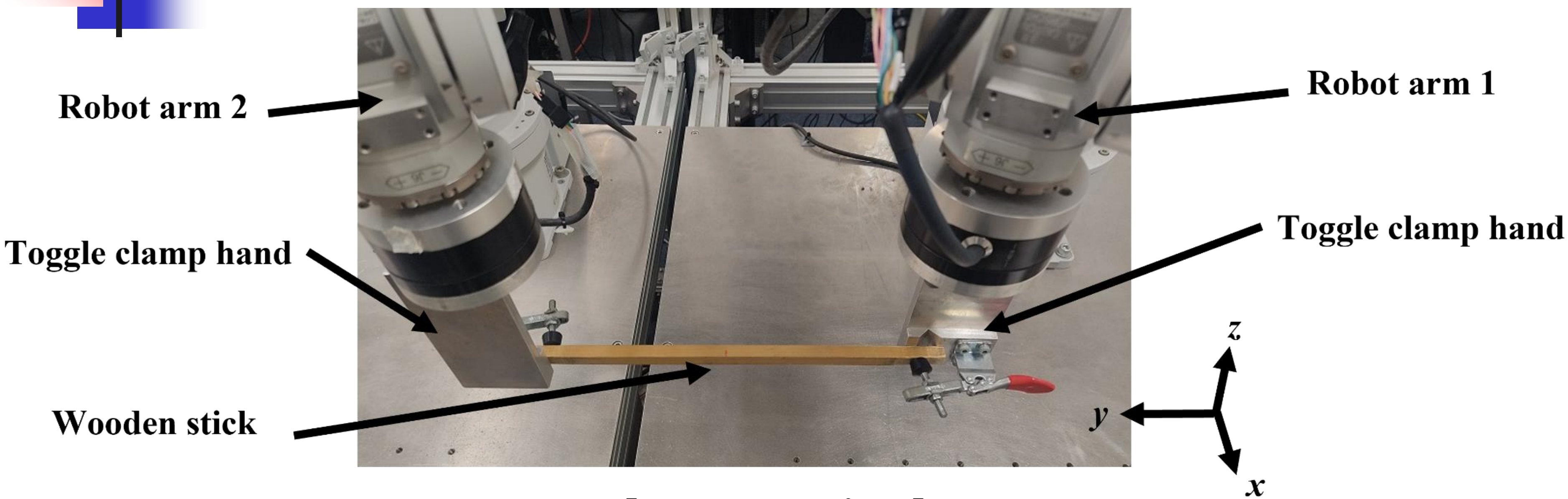
Experiment Method (1/3)



Master terminal

- **Each user operated a haptic interface device with his/her hand while watching video captured by the web camera in the two types of operations.**

Experiment Method (2/3)



Slave terminals

- **To move the wooden stick always in the same way, we used one system which automatically moves the robot arm (*robot arm 1*) in the front-back direction (i.e., the *x*-axis).**

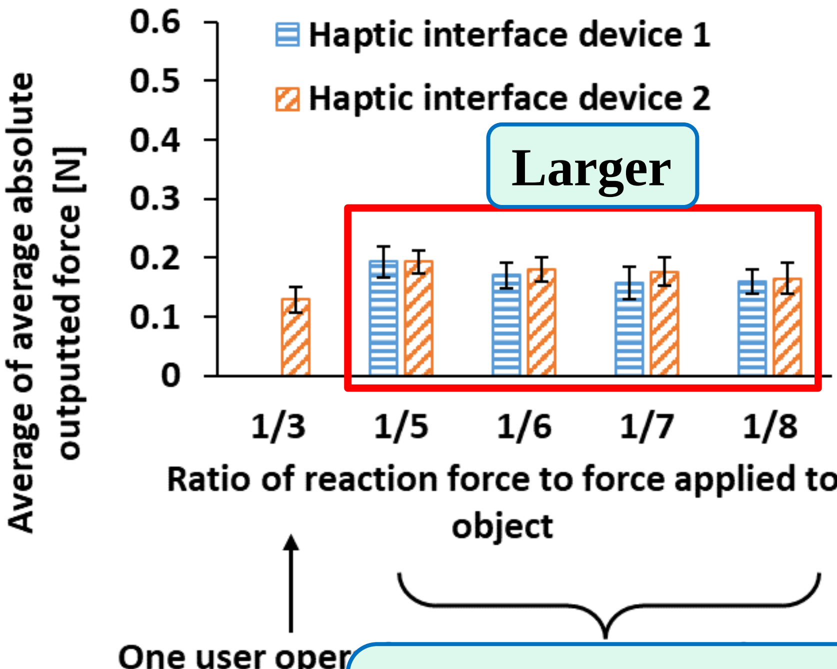
- **One or two users operated the other robot arm (*robot arm 2*) to move in the same way as robot arm 1.**

Experiment Method (3/3)

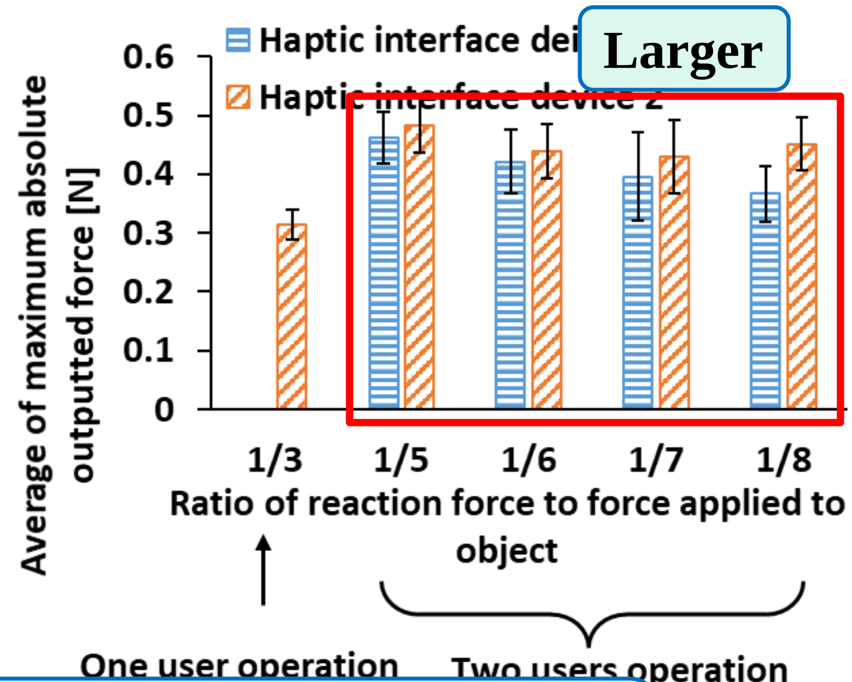
- $K_{\mathrm{scale}}^{(\mathrm{F})}$ in one user operation was set to 1/3.
- $K_{\mathrm{scale}}^{(\mathrm{F})}$ in two users operation was set to 1/5, 1/6, 1/7 and 1/8.
- Conducted 10 times for each value of $K_{\mathrm{scale}}^{(\mathrm{F})}$.
- Obtained the average and maximum absolute force of robot arm 2 (i.e., force applied to the stick) and outputted force presented to the user in both operations and calculated the average of the two measures for 10 times.

Experimental Results (1/4)

I: 95% confidence interval



I: 95% confidence interval



(a

Averages of two users operation are larger than those of one user operation.

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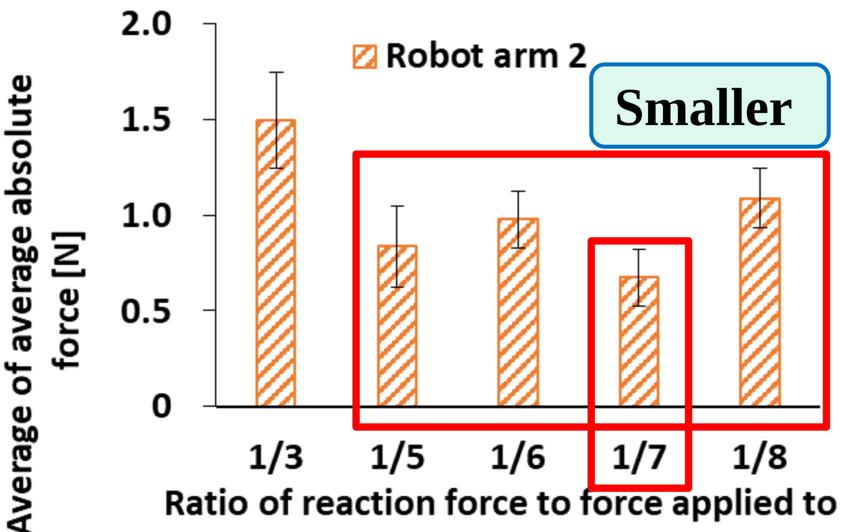
Average of average absolute outputted force and average of maximum absolute outputted force at haptic interface device.

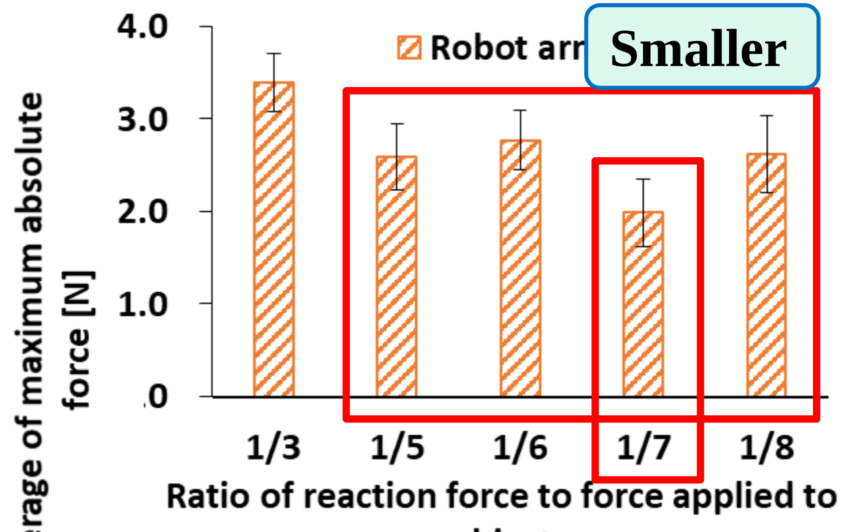
Experimental Results (2/4)

I: 95% confidence interval



One user operation

I: 95% confidence interval



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Averages of of 1/7 are the smallest in two users operation.

those of one user operation.

Since large force may damage the wooden stick, we need to keep the force small.

Two users operation outperforms one user operation in terms of the force applied to the object.

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force at

Conclusion

- We dealt with two types of operations in which an object is carried together by two remote robot systems with force feedback: one user operation and two users operation.
- We made a comparison between the two operations and clarified the optimum ratio of reaction force to the force applied to the object in two users operation.

➢ We found that compared with one user operation, two users operation has smaller force applied to the stick and larger outputted force presented to the user.

➢ There is the optimum value of the mapping scale about the force ($K_{\mathrm{scale}}^{(\mathrm{F})}$).

Future Work

- **We plan to examine the influence of the network delay in two users operation and compare it with that in one user operation.**