Comparison of Collaboration Methods between Users in Remote Robot Systems with Force Feedback

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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 arm through a haptic interface device (i.e., force feedback).

⬇

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

Background (2/2)

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) degradation

Instability phenomena occur

QoS control + Stabilization control

Previous Work (1/2)

*1 T. Abe *et al*., ICCE-TW, pp. 133-134, May 2018.

- **Operated a haptic interface device at a remote place by using a local one for collaboration between users.**[*1]**.**

→ **A calculation method of reaction force is used**

For collaboration between users, each user can perceive two kinds of force in the two remote robot systems with force feedback: Force sensed by force sensor and reaction force from the other user.

How to present the two kinds of force to each user has not been clarified so far.

Previous Work (2/2)

*2 S. Ishikawa *et al*., IJCNS, pp. 1-13, Mar. 2021.
*3 N. Hameedha *et al*., IJMERR, pp. 49-53, Feb. 2021.

- **Conducted cooperative work between users in the two remote robot systems with force feedback.[*2 *3]**

There are at least two relationships for collaboration between users in the two remote robot systems with force feedback: Equal relationship[*2] and master-slave relationship[*3].

The two relationships are handled between not users but the systems.

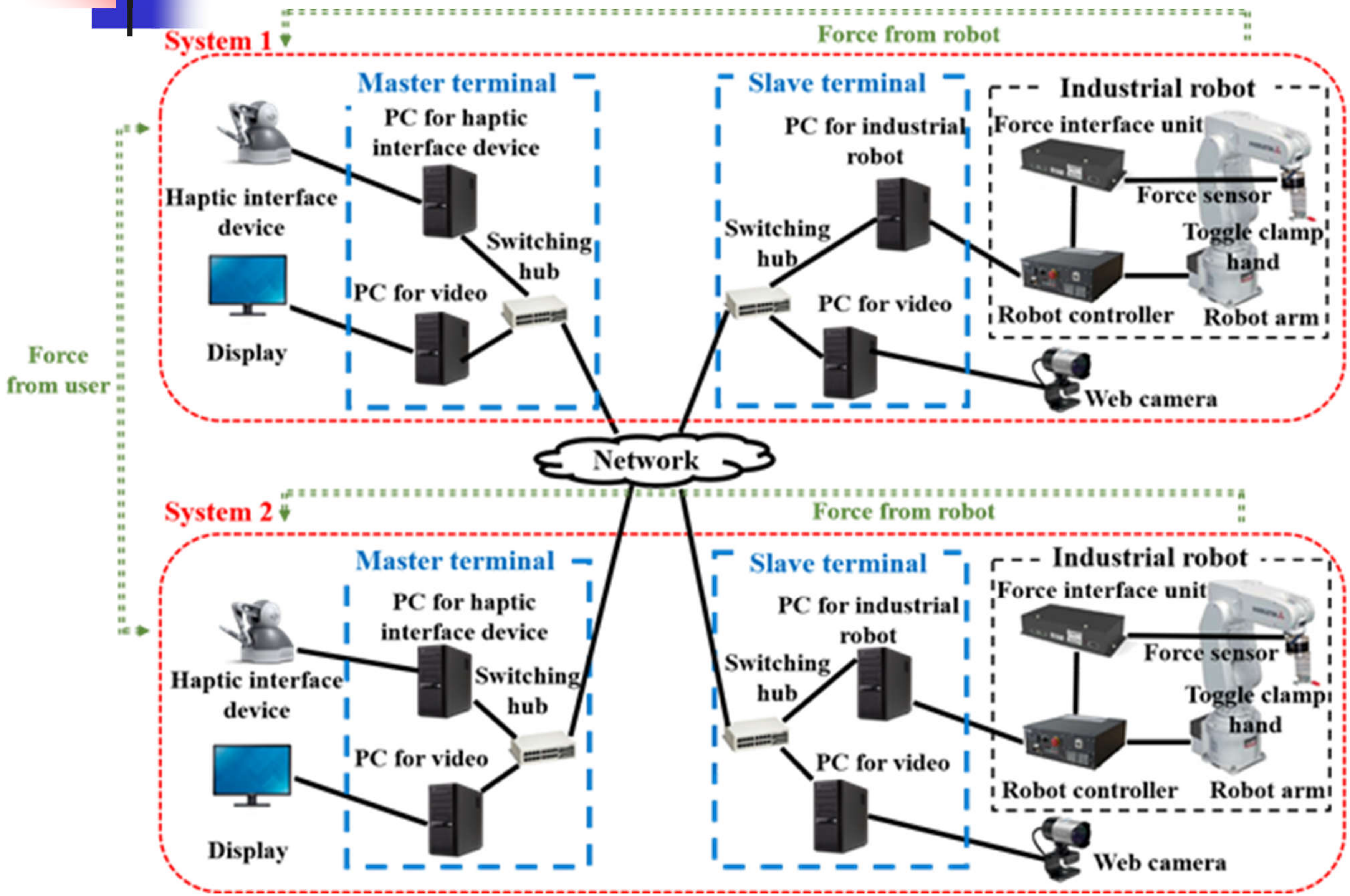
To deal with the relationships between users, we need to employ the two systems having the equal relationship.

Purpose

This work

- Deal with the equal and master-slave relationships between two users in two remote robot systems with force feedback which have the equal relationship.
- Make a comparison of collaboration methods in the two relationships between the users for cooperative work of carrying an object together by experiment.
- Change the ratio of the two kinds of force presented to each user for each relationship as collaboration methods and clarify preferable ratios for the users.

Remote Robot Systems with Force Feedback



Calculation of Reaction Force

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

Reaction Force Outputted at Master Terminal (called force from robot)

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

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

($K_{\mathrm{scale}}^{(\mathrm{F})} = 0.33$ [*2])

Calculation of Position

Position of Robot

$$\boldsymbol{S}_t = \boldsymbol{M}_{t-1} + \boldsymbol{V}_{t-1}$$

- $\boldsymbol{S}_t$: **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 arm at time t**

Collaboration Methods between Users (1/3)

Equal Relationship

- We suppose a fifty-fifty partnership between the two users.
- The users try to carry the object while helping each other.

Master-Slave Relationship

- One user behaves as a master, and the other user does as a slave.
- The master user tries to carry the object, and the slave user supports the work according to the movement by the master one.

Collaboration Methods between Users (2/3)

*1 T. Abe *et al.*, ICCE-TW, pp. 133-134, May 2018.

Reaction Force Outputted though Haptic Interface Device (in System 1) (called force from other)

Elastic — Viscosity

$$\boldsymbol{F}_t^{(\mathrm{m}_1)} = K_\mathrm{s}\left(\boldsymbol{P}_{t-1}^{(\mathrm{m}_2)} - \boldsymbol{P}_{t-1}^{(\mathrm{m}_1)}\right) + K_\mathrm{d}\left(\dot{\boldsymbol{P}}_{t-1}^{(\mathrm{m}_2)} - \dot{\boldsymbol{P}}_{t-1}^{(\mathrm{m}_1)}\right)^{*1}$$

Difference of position vector of two haptic interface devices

Difference of velocity vector of two haptic interface devices

- $\boldsymbol{F}_t^{(\mathrm{m}_1)}$: **Reaction force outputted though haptic interface device in system 1 at time *t* (*t* ≥ 1)**
- K_s: **Elastic coefficient = 0.1** K_d : **Viscosity coefficient = 0.0**

Collaboration Methods between Users (3/3)

Outputted Force though Haptic Interface Device (in System 1)

$$\boldsymbol{F}_t^{(\mathrm{m}_1)} = \alpha_1 \left\{ K_\mathrm{s} \left(\boldsymbol{P}_{t-1}^{(\mathrm{m}_2)} - \boldsymbol{P}_{t-1}^{(\mathrm{m}_1)} \right) + K_\mathrm{d} \left(\dot{\boldsymbol{P}}_{t-1}^{(\mathrm{m}_2)} - \dot{\boldsymbol{P}}_{t-1}^{(\mathrm{m}_1)} \right) \right\} + (1 - \alpha_1) \left(K_{\mathrm{scale}} \boldsymbol{F}_{t-1}^{(\mathrm{s}_1)} \right)$$

Outputted Force

Force from other

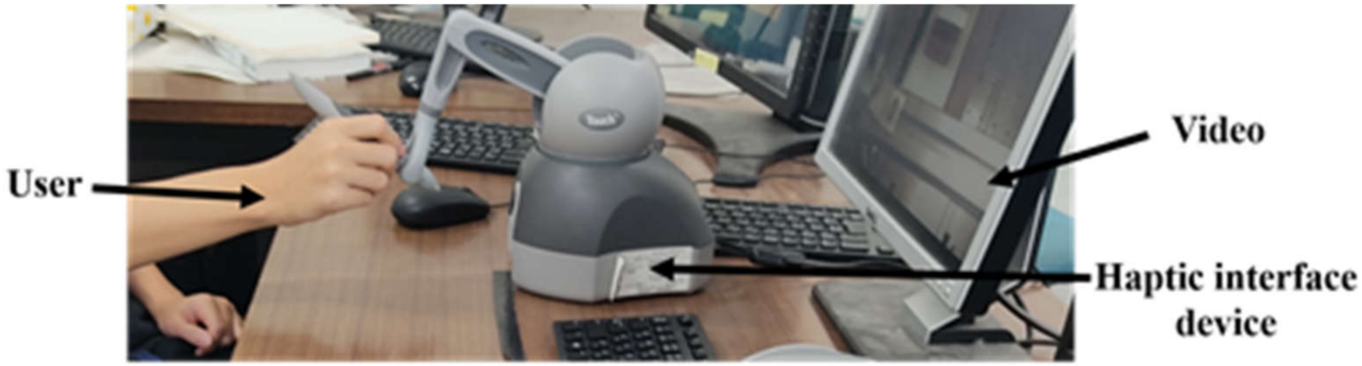
Force from robot

- α_1: **Parameter of ratio of two kinds of force in system 1**

◆ **Outputted force in system 2 is obtained in the same way as in system 1.**

- α_2: **Parameter of ratio of two kinds of force in system 2**

Experiment Method (1/3)



Each master terminal

- Each user operated a haptic interface device with his/her hand.
- One user conducted cooperative work of carrying a wooden stick together with the other user while watching video.

Experiment Method (2/3)

Two robot arms

- **To move the stick always in almost the same way in the experiment, building blocks were piled up ahead and behind the initial position of the stick.**

- **We used weights and metal bookends to prevent the building blocks from falling and the users could feel the force through haptic interface devices when the stick pushed the building blocks.**

Experiment Method (3/3)

- **Changed the ratio of the two kinds of force presented to each user by using several values of (α_1, α_2) :**
  (0, 0), (0, 0.5), (0, 1.0), (0.5, 0.5), (0.5, 1.0), and (1.0, 1.0).

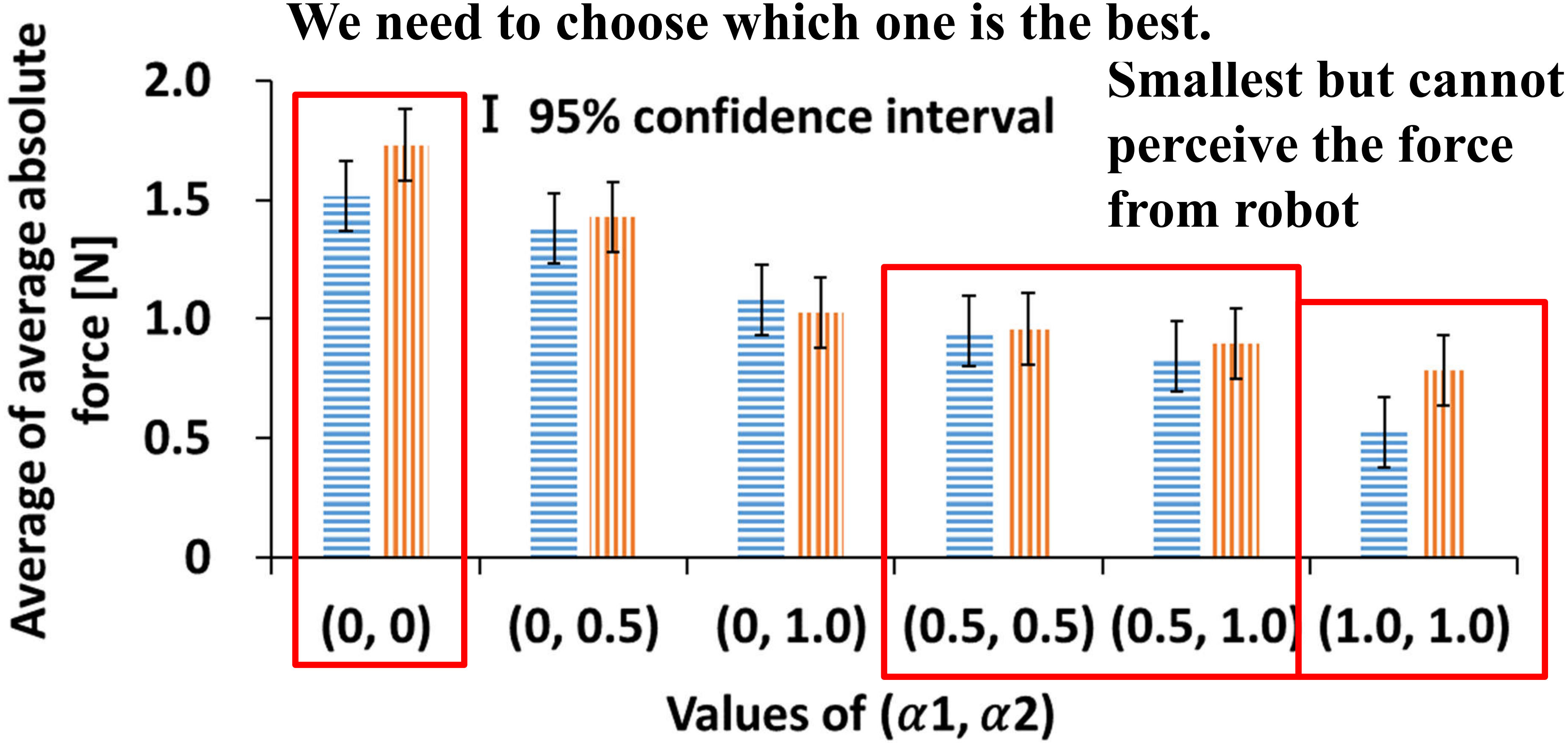
- **Conducted the experiment in the two relationships.**

- **Measured the force applied to the stick and obtained the average absolute force and calculated the average of the 10 times (*average of average absolute force*).**

Large force may damage the stick, smaller force is better.

Experimental Results (1/4)

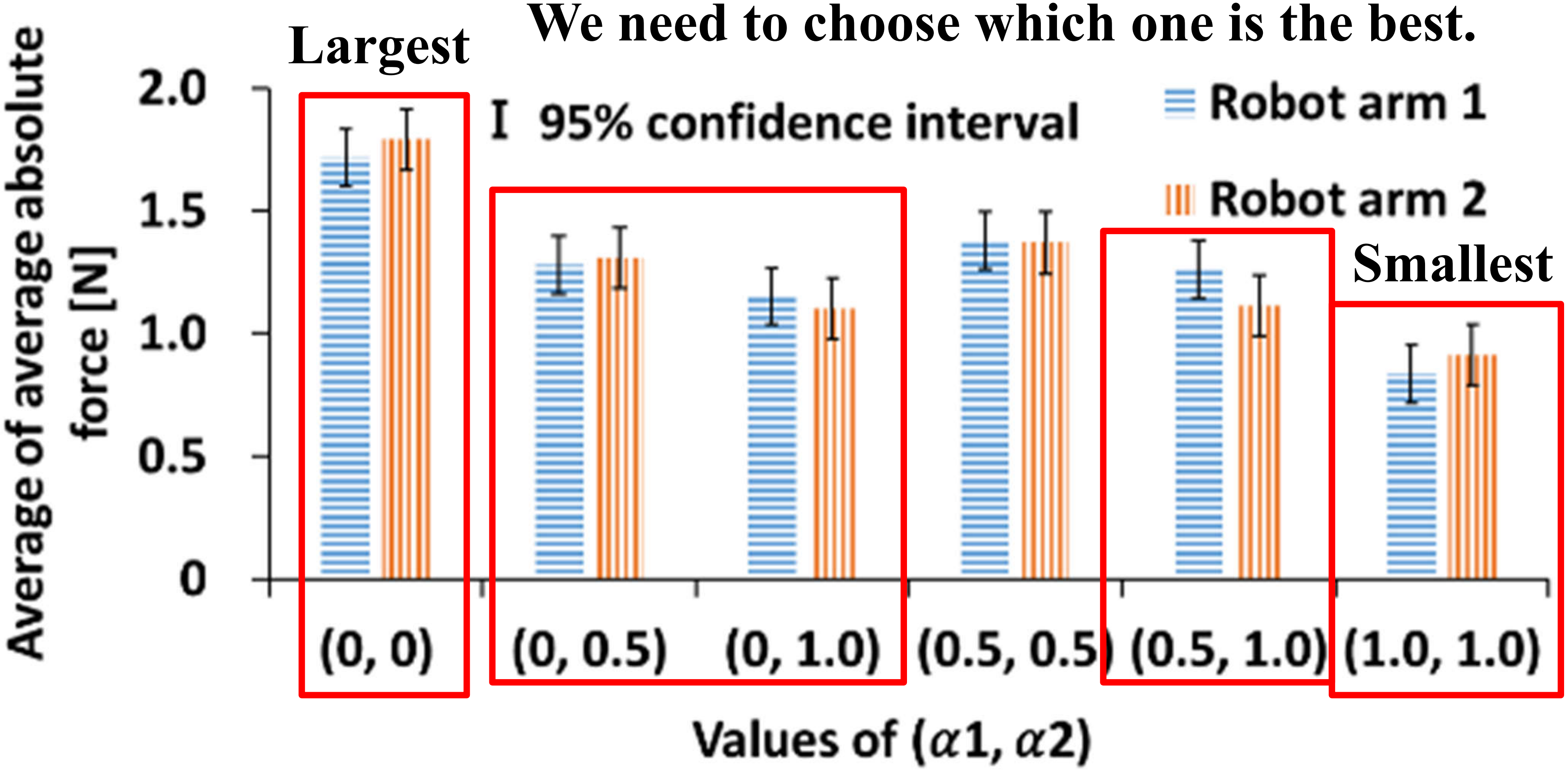
(0.5, 0.5) and (0.5, 1.0) are better.
We need to choose which one is the best.



Average of average absolute force of robot arms in equal relationship

Experimental Results (2/4)

(0, 0.5), (0, 1.0) and (0.5, 1.0) are better.
We need to choose which one is the best.



Average of average absolute force of robot arms
in master-slave relationship

Experimental Results (3/4)

(0.5, 0.5) is the best in the equal relationship.

Perception of two kind of force

Better combinations in the equal relationship according to average force

	robot		Force from user	
		User 2/ Slave user	User 1/ Master user	User 2/ Slave user
(0, 0)	Can strongly	Can strongly	Cannot	Cannot
(0, 0.	Can strongly	Can	Cannot	Can
(0, 1.0)	Can strongly	Cannot	Cannot	Can strongly
(0.5, 0.5)	Can	Can	Can	Can
(0.5, 1.0)	Can	Cannot	Can	Can strongly
(1.0, 1.0)	Cannot	Cannot	Can strongly	Can strongly

Experimental Results (4/4)

(0, 0.5) is the best in the master-slave relationship.

Better combinations in the master-slave relationship according to average force

...n of two kind of force

(α1, ...)	...m robot		Force from user	
	User 1/ Master user	User 2/ Slave user	User 1/ Master user	User 2/ Slave user
(0, ...)	Can strongly	Can strongly	Cannot	Cannot
(0, 0.5)	Can strongly	Can	Cannot	Can
(0, 1.0)	Can strongly	Cannot	Cannot	Can strongly
(0.5, 0.5)	Can	Can	Can	Can
(0.5, 1.0)	Can	Cannot	Can	Can strongly
(1.0, 1.0)	Cannot	Cannot	Can strongly	Can strongly

Conclusion

- **We made a comparison between collaboration methods between users on cooperative work.**
- **We handled the equal and master-slave relationships between the two users.**
- **We changed the ratio of the two kinds of force presented to each user in each relationship as the collaboration methods.**

➢ **The two users should perceive the two kinds of force in the same way in the equal relationship.**

➢ **The master user should perceive the force from robot, and the slave user should feel the two kinds of force in the master-slave relationship.**

Future Work

- Investigate the effect of network delays in the two remote robot systems.
- Obtain the optimum ratio of the two kinds of force presented to each user.
- Improve the accuracy of cooperative work by using audio and visual information as well as force information for collaboration between users.