Collaboration between Users with Haptics in Remote Robot Systems

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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 arms through haptic interface devices (i.e., force feedback).

⬇

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

Background (2/2)

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 R. Ye *et al.*, Proc. ICCC, Dec. 2021.

- **Dealt with the equal and master-slave relationships between two users in cooperative work of carrying a wooden stick together for two remote robot systems with force feedback[*1].**

Examined how to present two types of force (force from user and force from robot) by experiment.

Discussed only the force applied to the stick, but not the force presented to the users

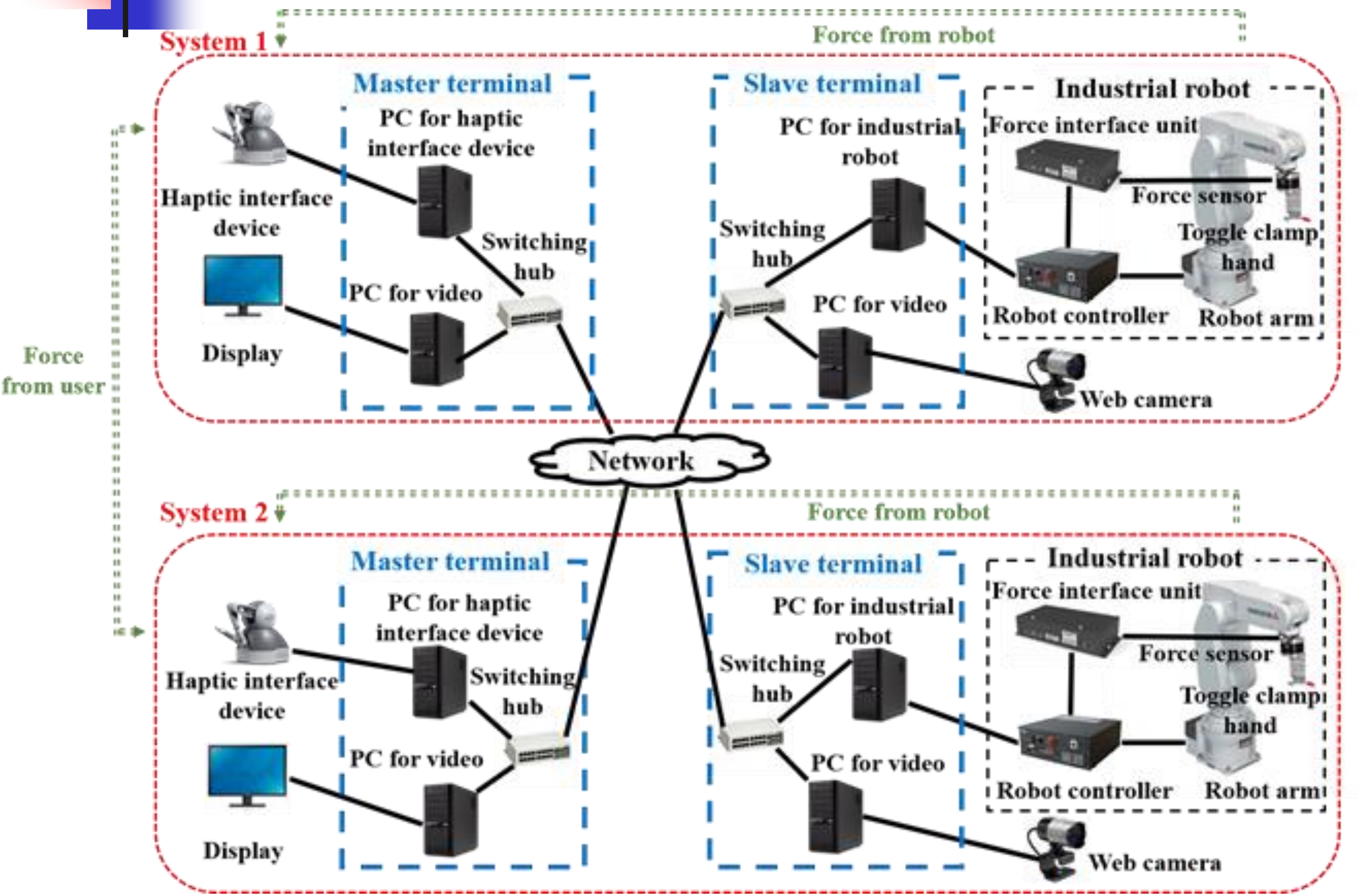
It is important to investigate the force presented to each user, and it has not been clarified so far.

Purpose

This work

- Deal with the equal and master-slave relationships between two users in cooperative work of carrying a wooden stick together for two remote robot systems with force feedback.
- Examine the force presented to each user in the cooperative work.
- Change the ratio of the two kinds of force presented to each user for each relationship and clarify how to present the two kinds of force to each user.

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* ≥ 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

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

Position of Robot

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

- $\boldsymbol{S}_t$ **: 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 haptic interface device at time *t***
- $K_{\mathrm{scale}}^{(\mathrm{P})}$ **: Mapping scale about position between industrial robot and haptic interface device**

$\left(K_{\mathrm{scale}}^{(\mathrm{P})} = 0.5\right.$ ***2** $\left.\right)$

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)

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

$\boldsymbol{F}_t^{(\mathrm{m_i})}$: **Reaction Force Outputted though Haptic Interface Device in System i (i=1 or 2) at time *t* (*t* ≥ 1) (called force from user)**

Elastic (spring) — **Viscosity (damper)**

$$\boldsymbol{F}_t^{(\mathrm{m_1})} = K_\mathrm{s}\left(\boldsymbol{P}_{t-1}^{(\mathrm{m_2})} - \boldsymbol{P}_{t-1}^{(\mathrm{m_1})}\right) + K_\mathrm{d}\left(\dot{\boldsymbol{P}}_{t-1}^{(\mathrm{m_2})} - \dot{\boldsymbol{P}}_{t-1}^{(\mathrm{m_1})}\right)$$ ***3**

Difference of position vector of two haptic interface devices

Difference of velocity vector of two haptic interface devices

- K_s: **Elastic coefficient = 0.1** K_d : **Viscosity coefficient = 0.0**

Collaboration Methods between Users (3/3)

$\boldsymbol{F}_t^{(\mathrm{m_i})}$: **Outputted Force though Haptic Interface Device (in System i)**

Force from user

$$\boldsymbol{F}_t^{(\mathrm{m_1})} = \alpha_1 \left\{ K_\mathrm{s} \left(\boldsymbol{P}_{t-1}^{(\mathrm{m_2})} - \boldsymbol{P}_{t-1}^{(\mathrm{m_1})} \right) + K_\mathrm{d} \left(\dot{\boldsymbol{P}}_{t-1}^{(\mathrm{m_2})} - \dot{\boldsymbol{P}}_{t-1}^{(\mathrm{m_1})} \right) \right\} + (1 - \alpha_1) \left(K_\mathrm{scale} \boldsymbol{F}_{t-1}^{(\mathrm{s_1})} \right)$$

Outputted Force

Force from robot

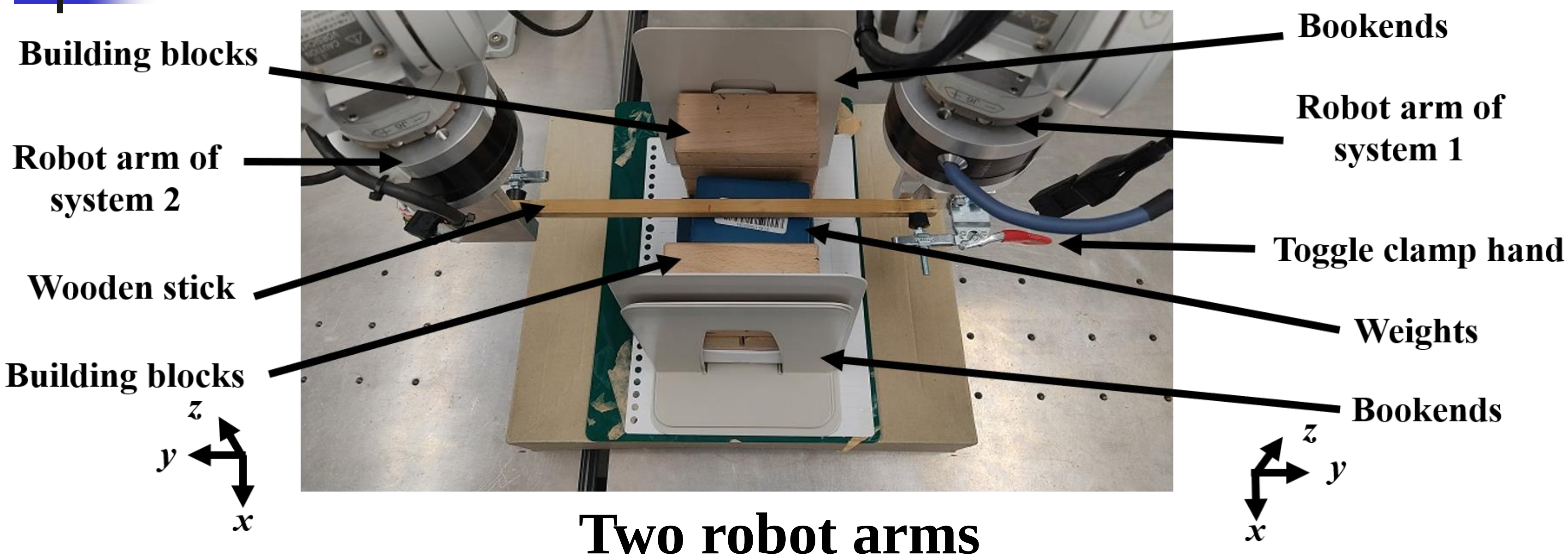
- α_i: **Parameter of ratio of two kinds of force in system i**

Experiment Method (1/4)

Each master terminal

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

Experiment Method (2/4)



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 so that the users could feel the force easily through haptic interface devices when the stick pushed the building blocks.

Experiment Method (3/4)

Demo video

- The users moved the stick toward the building blocks to push the blocks while keeping the robot arms parallel to each other.

- To move the stick at almost the same velocity, users pushed the first building block at about 5 seconds from the beginning of each work and the second block at around 15 seconds.

Experiment Method (4/4)

*1 R. Ye *et al*., Proc. ICCC, Dec. 2021.

- **Network delay between systems was set to 0 millisecond.**
- **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) [*1].**
- **Conducted the experiment 10 times in the equal and master-slave relationships.**
- **Measured the three types of force (outputted force, force from user, and force from robot) during the work.**
- **Obtained the average of the 10 times for each type of force.**

Experimental Results (1/3)

*1 R. Ye *et al.*, Proc. ICCC, Dec. 2021.

Take three preferable combinations into consideration[*1]

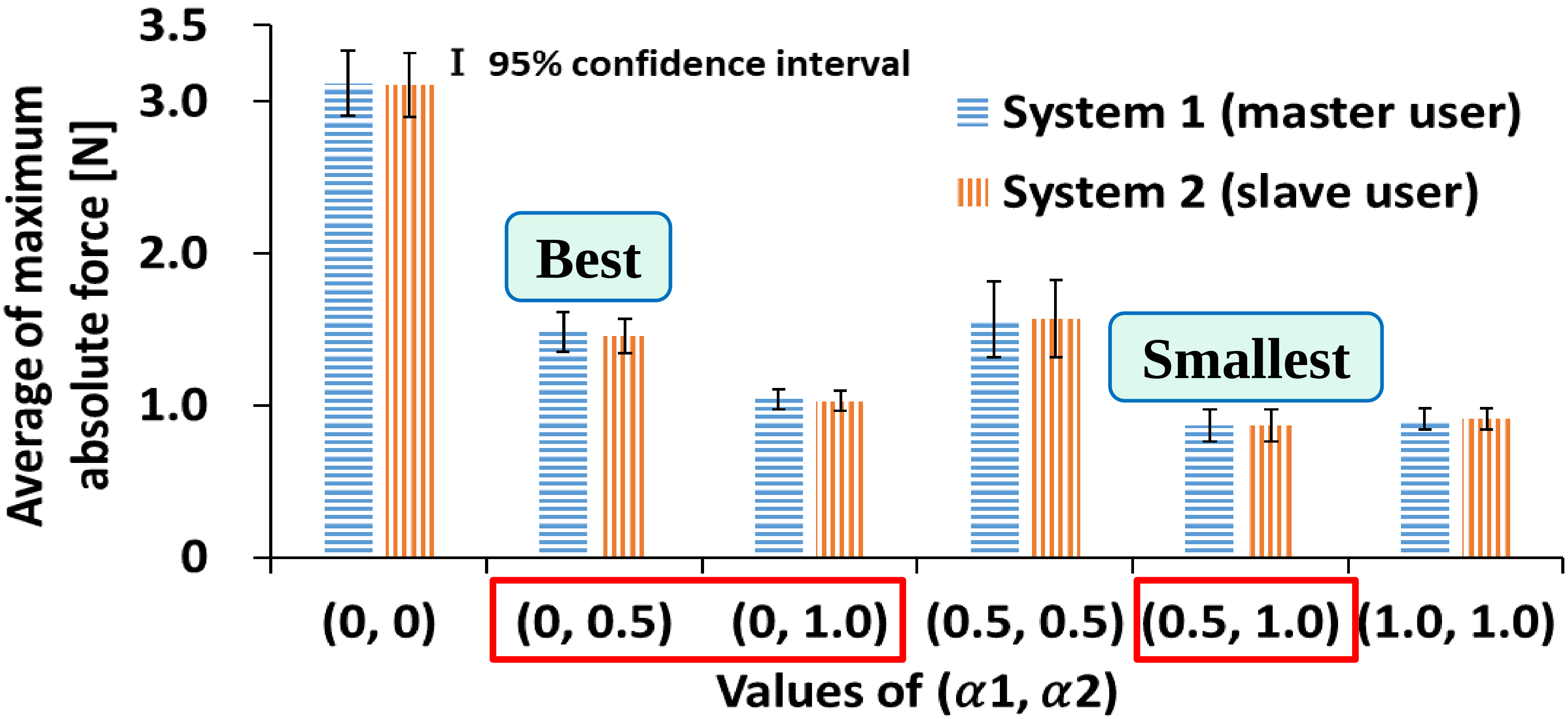
Three combinations are not largely different from each

We need to judge through other figures to find the best combination.

Average of maximum absolute outputted force in master-slave relationship

Experimental Results (2/3)

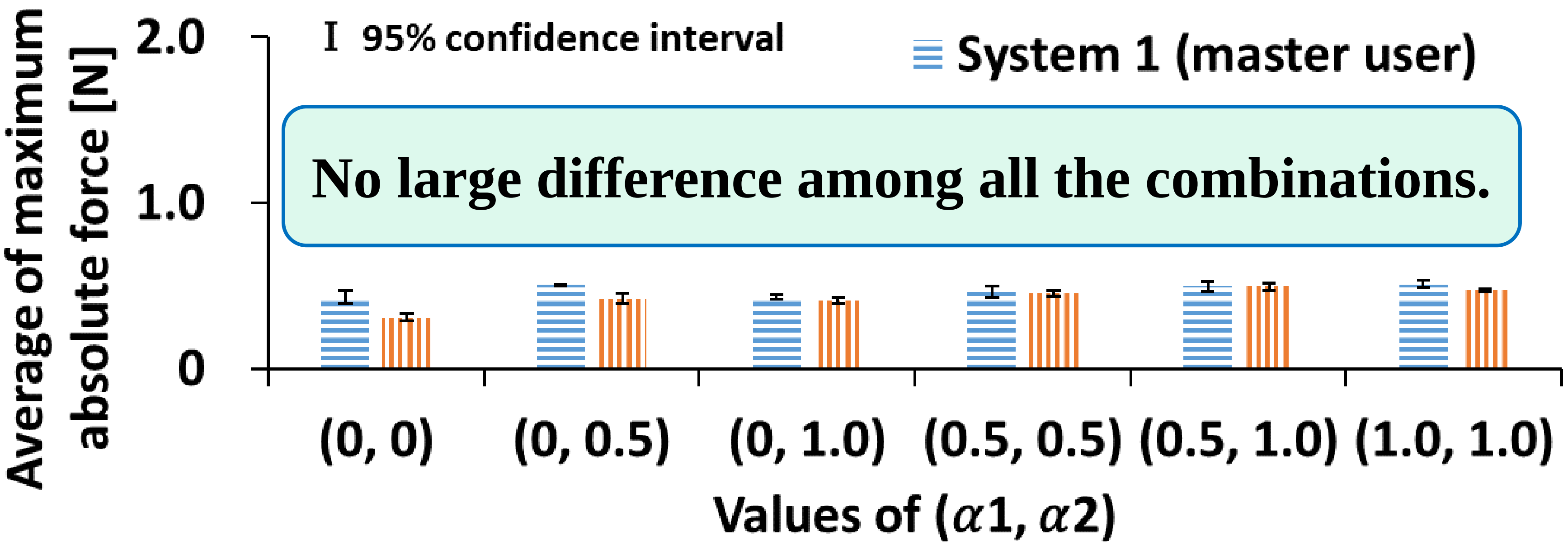
In this figure, (0, 0.5) is the best in three combinations



Average of maximum absolute force from user in master-slave relationship

Experimental Results (3/3)

Consider the three figures comprehensively (0, 0.5) is the best in the master-slave relationship.



Average of maximum absolute force from robot in master-slave relationship

Conclusion

- **We examined how to present the two kinds of force (force from user and force from robot) presented to the users in equal and master-slave relationships**

➢ **In the master-slave relationship, the master user should perceive the force from robot, and the slave user should feel the two kinds of force ((α_1,α_2) = (0, 0.5) is the best).**

➢ **In addition, the two users should perceive the two kinds of force in the same way in the equal relationship ((α_1,α_2) = (0.5, 0.5) is the best).**

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.**