One User Operation Versus Two Users Operation in Cooperative Remote Robot Systems

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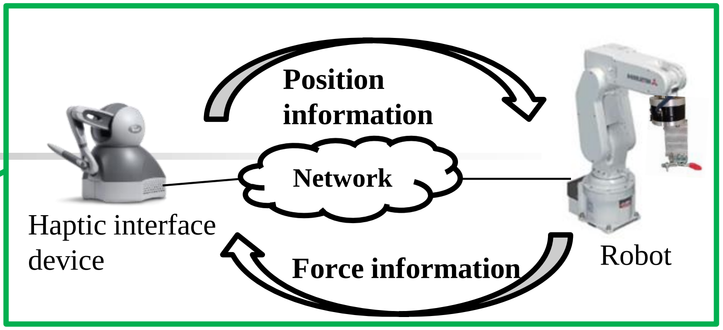
Background (1/2)



By using a remote robot system with force feedback, various tasks can be performed efficiently.

The force feedback helps a user of the system to feel the force that is sensed by a force sensor attached to a robot.

The user can react to the force via a haptic interface device.

Background (2/2)

When force information is transmitted over a network such as the Internet

Network delay, delay jitter and packet loss

Seriously damage
QoE (Quality of Experience)

QoS control is needed.

Previous Work

*1 T. Hagiwara *et al*., iScience, Nov. 2020.
*2 T. Hashimoto *et al*., NetGames, Oct. 2006.

- **Carried out tasks by controlling an avatar together in a virtual environment and found that two users perform better than one user.**[*1]
- **Demonstrated that in a networked haptic game, a player with the smaller delay can help the other player (i.e., a teammate) with the higher delay.**[*2]

↓

The findings may be reproduced in the remote robot system with force feedback.

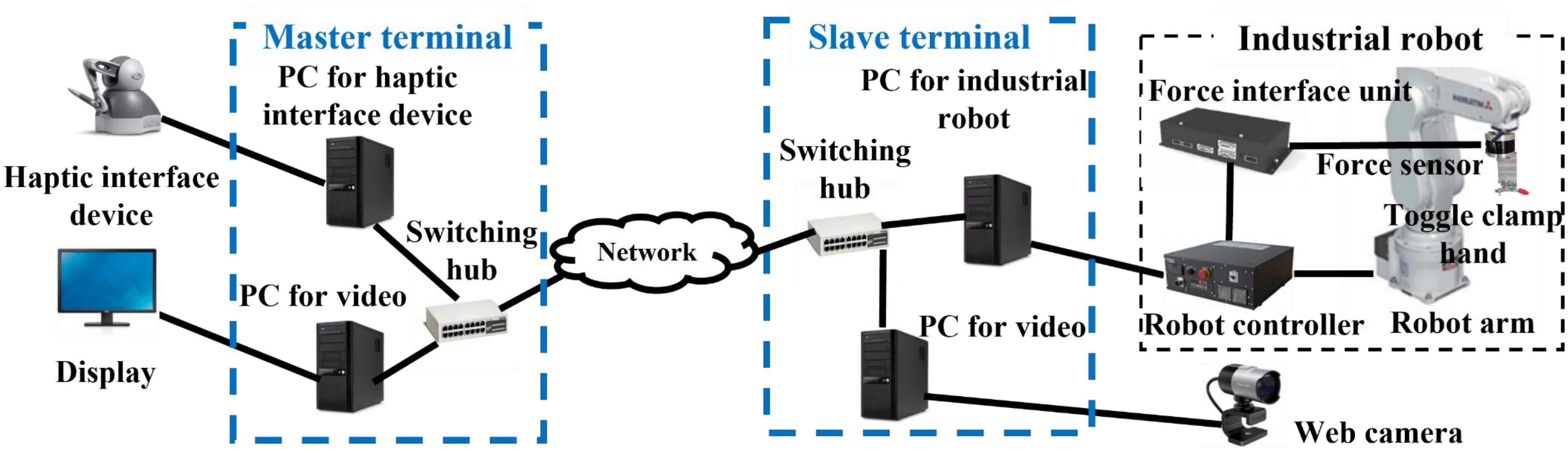
Such a kind of study has not been carried out so far.

Purpose

This work

- **Find out if two users operation is more efficient than one user operation.**
- **Find out if the user with smaller delay can help the other user.**

Remote Robot System with Force Feedback



System configuration of one user operation

Calculation of Force

*3 R. Ye *et al.*, ITE Technical Report, Dec. 2022.

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

- $\boldsymbol{F}_t^{(\mathrm{m})}$ **: 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** ($K_{\mathrm{scale}}^{(\mathrm{F})} = 0.33$ ***3**)

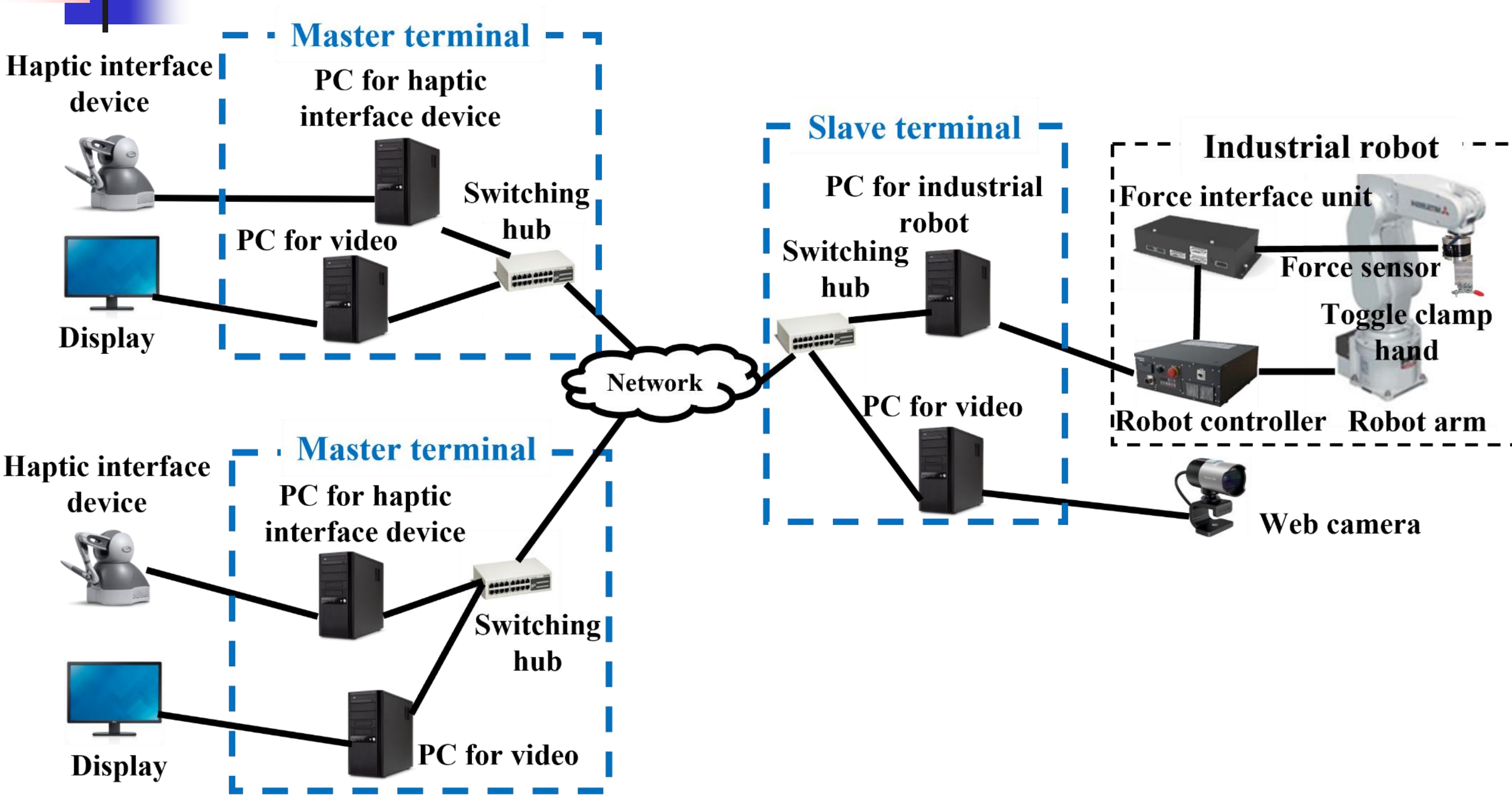
Calculation of Position

*3 R. Ye *et al*., ITE Technical Report, Dec. 2022.

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

- $\boldsymbol{S}_t$: **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***
- $K_{\text{scale}}^{(\mathrm{P})}$: **Mapping scale about position between industrial robot and haptic interface device** ($K_{\text{scale}}^{(\mathrm{P})} = 0.5$ *3)

Two Users Operation (1/2)



System configuration of two users operation

Two Users Operation (2/2)

*3 R. Ye *et al.*, ITE Technical Report, Dec. 2022.

Calculation of Force

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

- $\boldsymbol{F}_t^{(\mathrm{m}_i)}$ **: Force outputted at master terminal *i* (*i* = 1 or 2) at time *t* (*t* ≥ 1)**
- $K_{\mathrm{scale}}^{(\mathrm{F})} = 0.142$ *3

Calculation of Position

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

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

Experiment Method (1/2)

- **Each user operated the haptic interface device with his/her hand while watching video.**

- **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 moved the other robot arm (*robot arm 2*) in the same way as robot arm 1.**

- **In two users operation, we dealt with one user employing both hands and two different users.**

- **Same additional delay case**: the additional delay was set to the same as that in **the one user operation**.
- **Different additional delay case**: the additional delay for one user was set to 0 ms, and that for the other user was changed from 0 ms to 600 ms at intervals of 50 ms or 100 ms.

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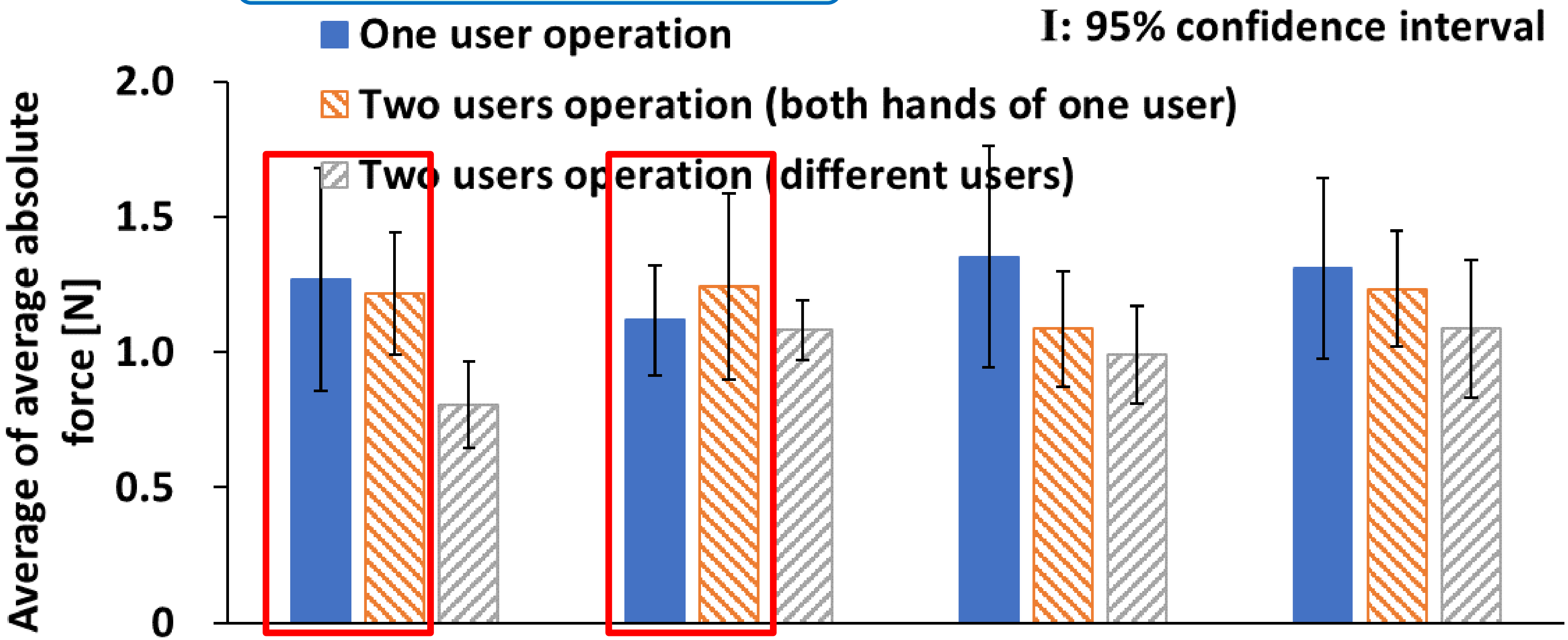
- **For one user operation, the additional delay was increased from 0 ms to 300 ms at intervals of 50 ms or 100 ms.**

- **For two users operation**
  - **Same additional delay case**
  - **Different additional delay case**

- **Conducted 10 times for each combination of the additional delay and obtained the average and maximum absolute force of robot arm and calculated the average of the two measures for 10 times (referred to as the *average of average absolute force* and *average of maximum absolute force*, respectively).**

Experimental Results (1/2)

No significant differences

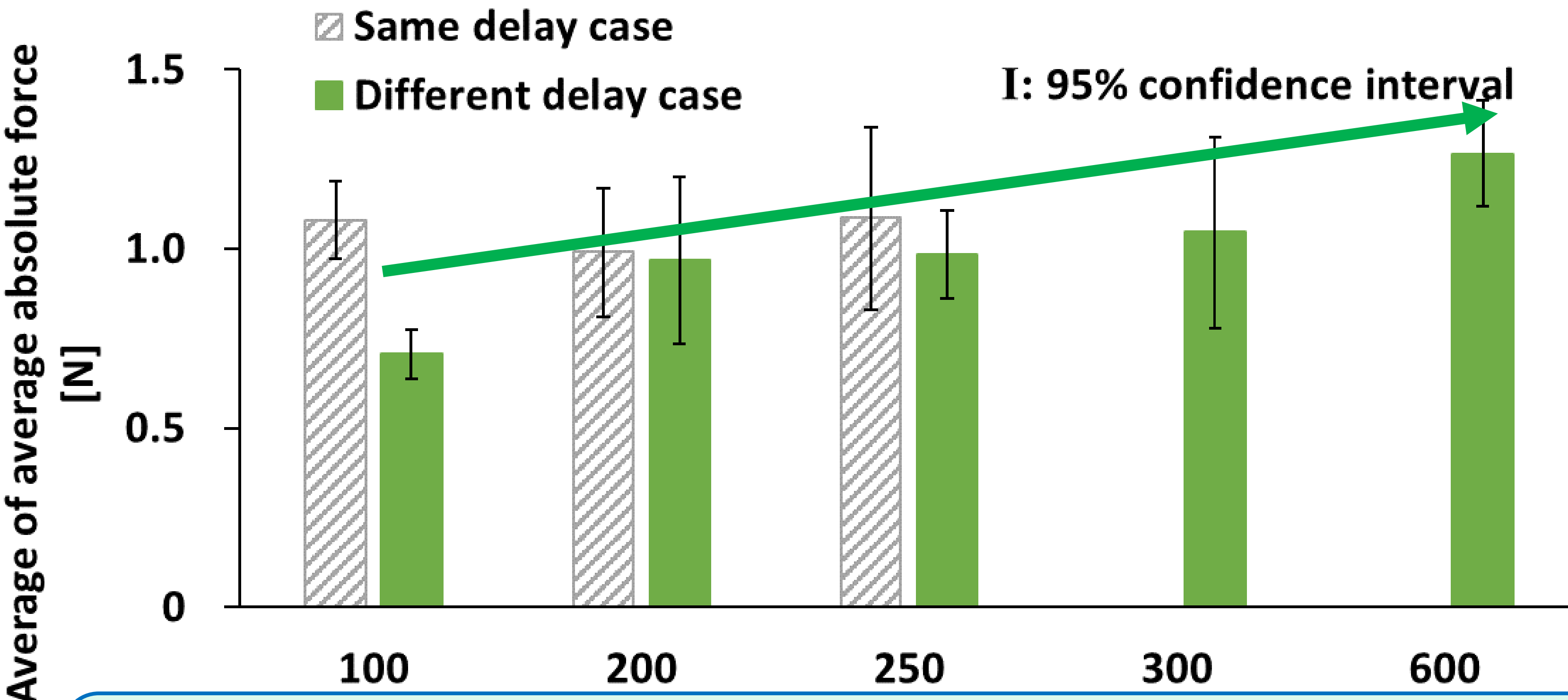


Since large force may damage the carried object, the two users operation outperforms the one user operation in terms of the force applied to the object.

smallest except when the additional delay is 100 ms.

Average of average force in the same additional delay case.

Experimental Results (2/2)



This result shows that when two users have different network delays

The average of average absolute force in the different additional delay case tends to become larger as the additional delay increases.

Average of average force for the two users operation in the two cases.

Conclusion and Future Work

Conclusion

- We compared the two users operation with the one user operation of a remote robot system with force feedback under network delays by experiment.

⬇

➢ We found that the two users operation outperforms the one user operation.

Future Work

- It is necessary to investigate how largely the two users operation is superior to the one user operation by QoE assessment.