QoE Assessment of Single-User Operation and Dual-User Operation in Remote Robot Systems with Force Feedback

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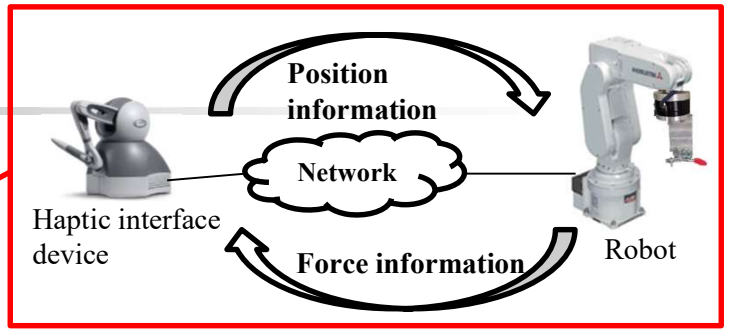
Background (1/2)



A remote robot system with force feedback has a variety of applications such as remote surgery and remote rehabilitation.

Since a user of the system can feel force from a remote robot having a force sensor through a haptic interface device.

The user can operate a remote robot effectively.

*1 R. Ye *et al.*, IEEE ICCE-TW, July 2023.

*2 S. Ishikawa *et al.*, IJCNS, pp. 99-111, Mar. 2021.

Background (2/2)

When position/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

QoS control[*1] **+ Stabilization control**[*2]

Previous Work (1/2)

- **Made a comparison between single-user operation and dual-user operation of a single remote robot for cooperative work of carrying an object between two remote robot systems with force feedback by experiment [*1].**

- **Illustrated that the dual-user operation outperforms the single-user operation in terms of force applied to the object.**
- **The dual-user operation can suppress the force more effectively.**

*1 R. Ye *et al.*, IEEE ICCE-TW, July 2023.

Previous Work (2/2)

Problem

QoE subjective comparison between the two operations has not been clarified so far [*1, *3].

- **Because subjective operability of haptic interface device is important, we need to clarify which operation is better than the other.**

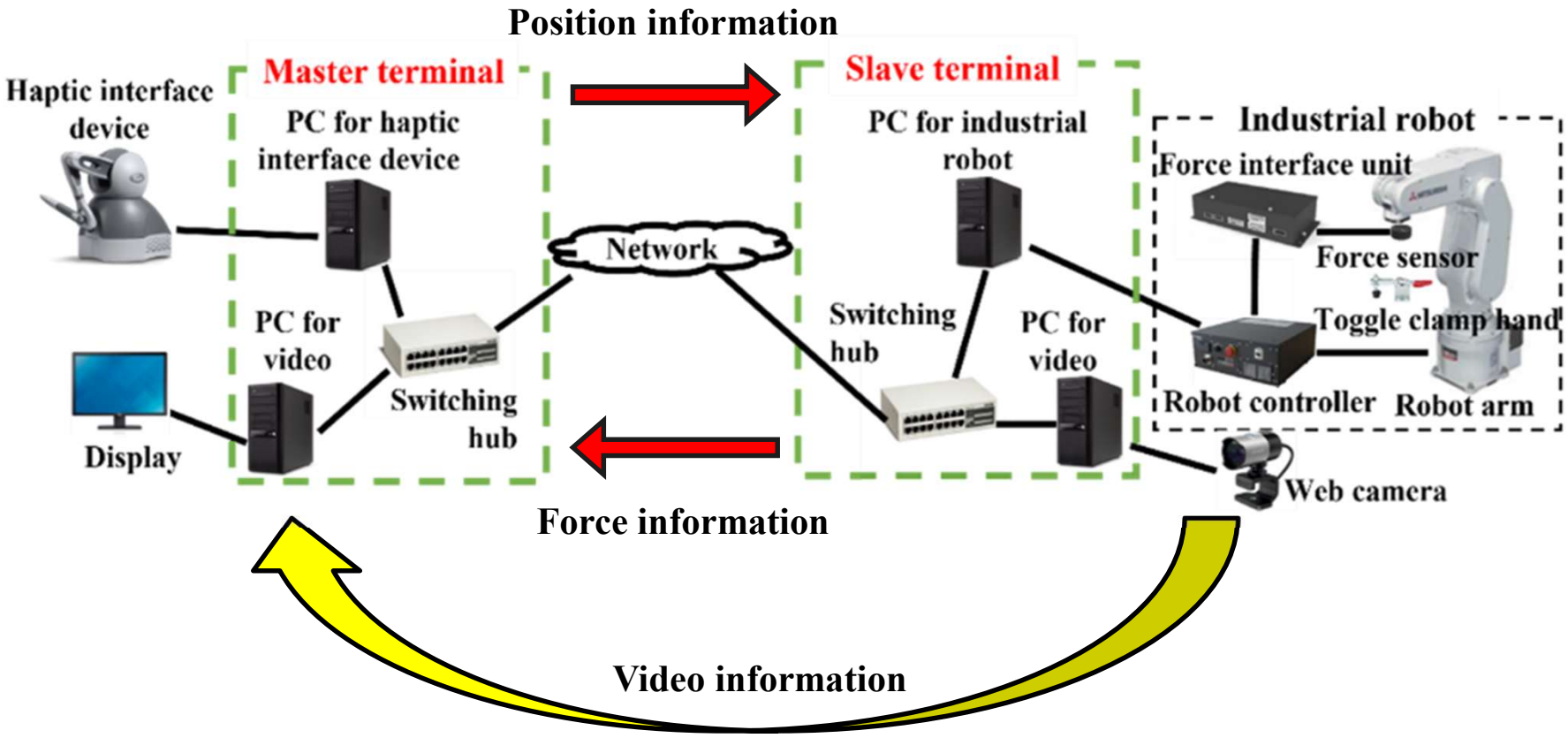
*1 R. Ye *et al*., IEEE ICCE-TW, July 2023.
*3 T. Hagihara *et al*., iScience, vol. 23, Nov. 2020.

Purpose

This work

- **Make a subjective comparison between the single-user operation and dual-user operation by QoE assessment.**
- **Examine the influence of network delays between the haptic interface devices and remote robot.**

Remote Robot Systems with Force Feedback



System configuration of single-user operation

Calculation of Position

- **The robot arm is moved according to the position information by using the following equation [*1].**

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

$\boldsymbol{S}_t$: Position vector of robot at time t $(t \geq 1)$

$K_{\text{scale}}^{(\text{P})}$: Mapping scale about position between robot arm and haptic interface device

$\boldsymbol{M}_t$: Position vector of robot arm from haptic interface device at time t

$\boldsymbol{V}_t$: Moving velocity of robot arm at time t

*1 R. Ye *et al.*, IEE ICCE-TW, July 2023.

Calculation of Force

- **The user feels the force $\boldsymbol{F}_t^{(\mathrm{m})}$ which is output through the device of the master terminal at time t by using the following equation [*1].**

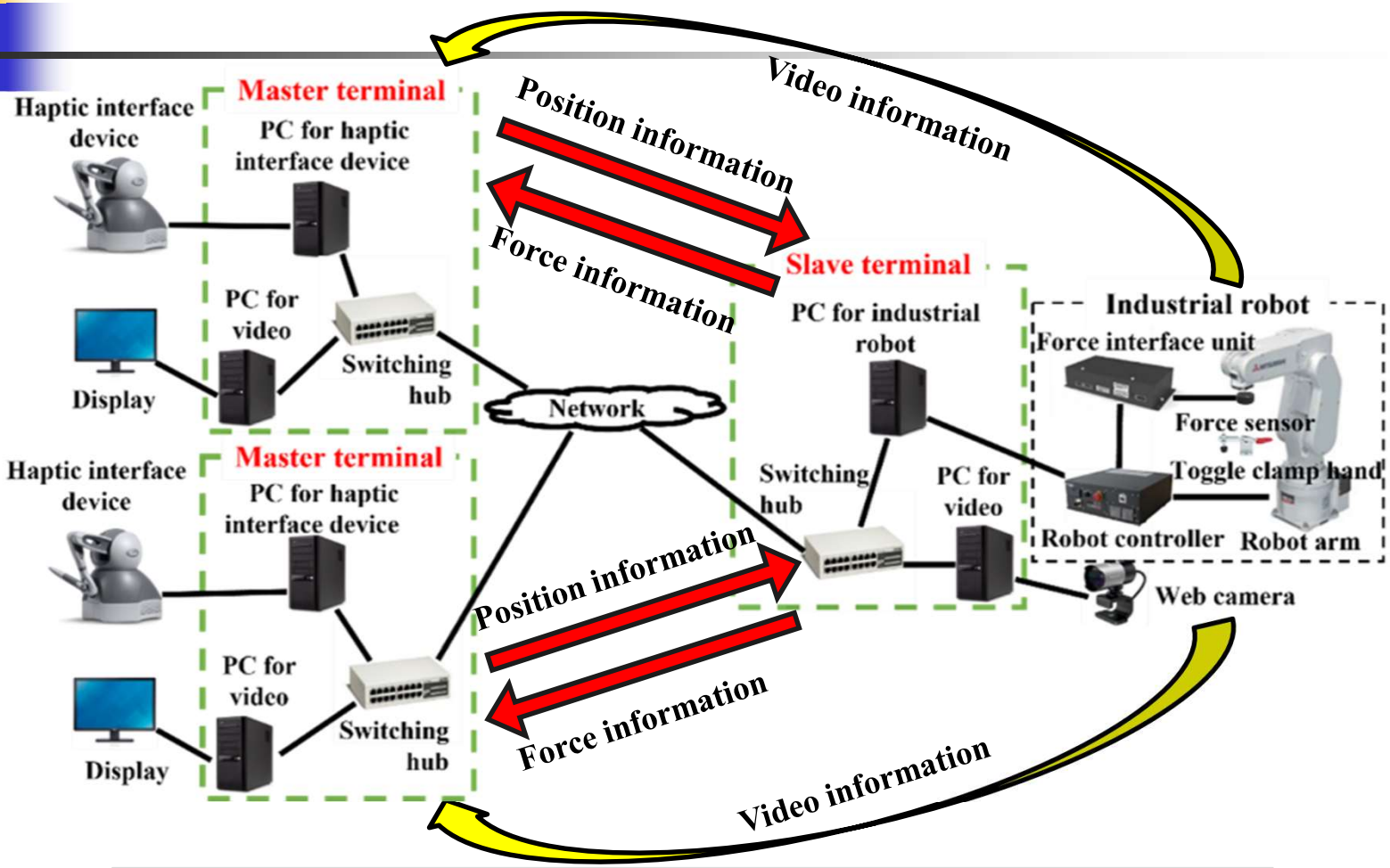
$$\boldsymbol{F}_t^{(\mathrm{m})} = K_{\mathrm{scale}}^{(\mathrm{F})} \boldsymbol{F}_{t-1}^{(\mathrm{s})}$$

$K_{\mathrm{scale}}^{(\mathrm{F})}$: Mapping scale about force between robot arm and haptic interface device

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

*1 R.Ye *et al.*, IEEE ICCE-TW, July 2023.

Dual-User Operation



System configuration of dual-user operation

Each user of the master terminal feels the force while watching video as in the single-user operation.

Calculation of Position and Force

- **The position of the robot arm is determined by the following equation*[1].**

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

$\boldsymbol{S}_t$: Position vector of robot at time t $(t \geq 1)$

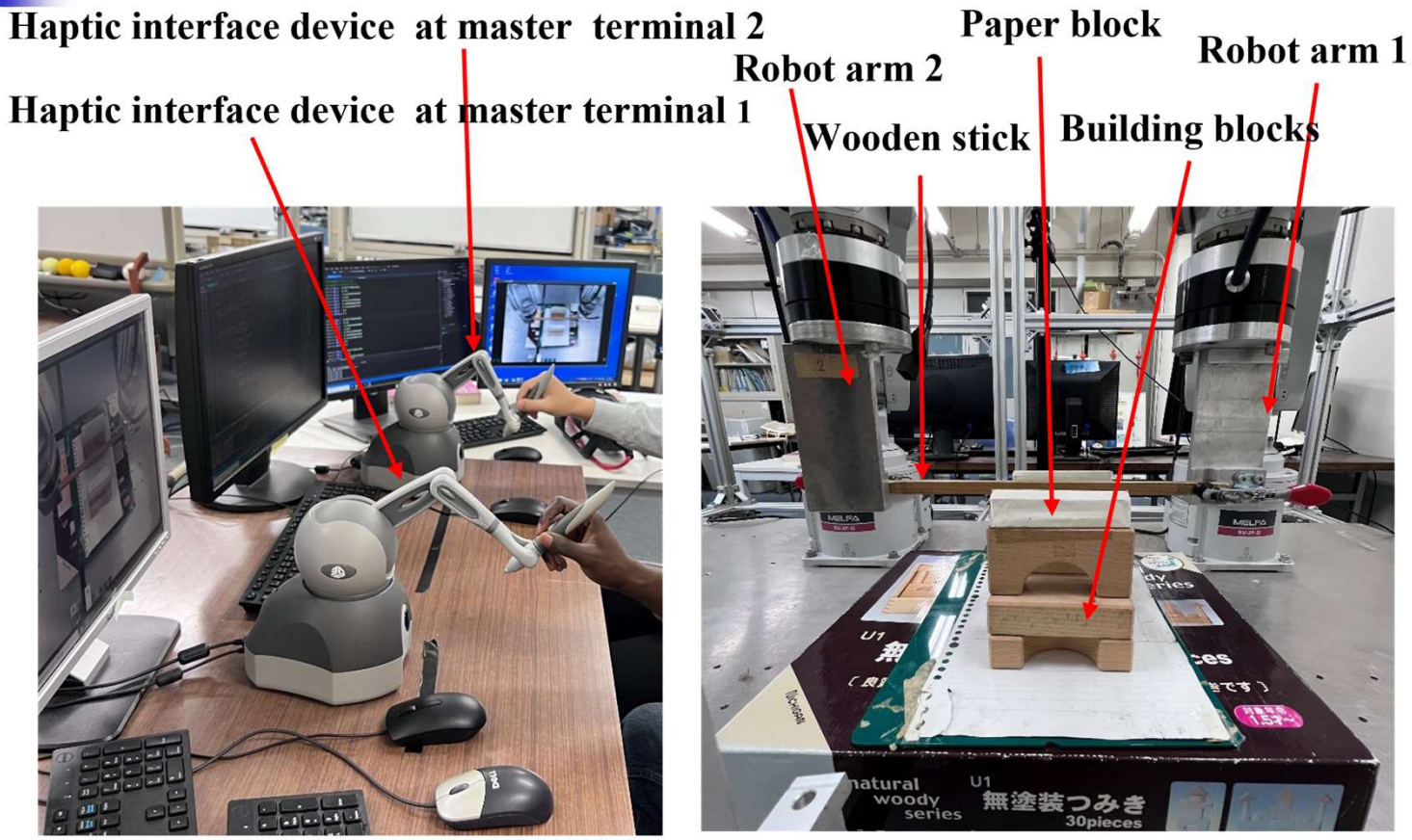
$K_{\text{scale}}^{(\text{P})}$: Mapping scale about position between robot arm and haptic interface device

$\boldsymbol{M}_t^{(\text{m}_i)}$: Position vector of haptic interface device at master terminal i (i = 1 or 2) at time t

$\boldsymbol{V}_t$: Moving velocity of robot arm at time t

*1 R.Ye *et al.*, IEEE ICCE-TW, July 2023.

Assessment Method (1/3)



(a) Operation of haptic interface devices

(b) Camera view of robot arms

Cooperative work in dual-user operation

Assessment Method (2/3)

Dual-user operation

- We changed the network delays between the haptic interface device at master terminal i (i =1 or 2) and robot arm 2 (called *network delay* i).
- We denote a combination of the network delays by (network delay 1, network delay 2) in the dual-user operation.

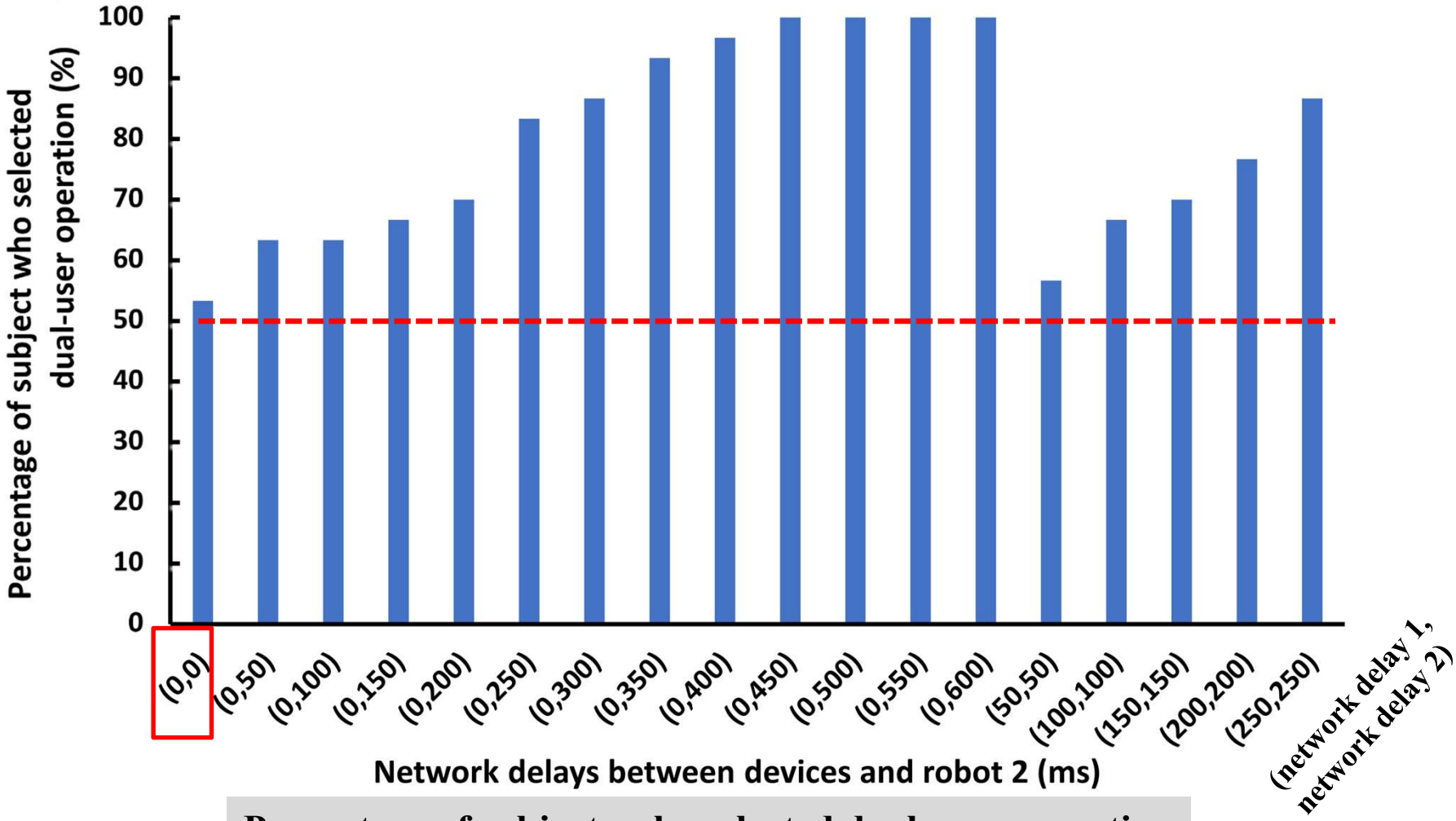
Single-user operation

- Only network delay 2 was presented to each subject.
- Network delay 1 was set to 0 ms, and network delay 2 was changed 0 ms to 600 ms at intervals of 50 ms.
- We also changed the two network delays at the same time from 0 ms to 250 ms at intervals of 50 ms.

Assessment Method (3/3)

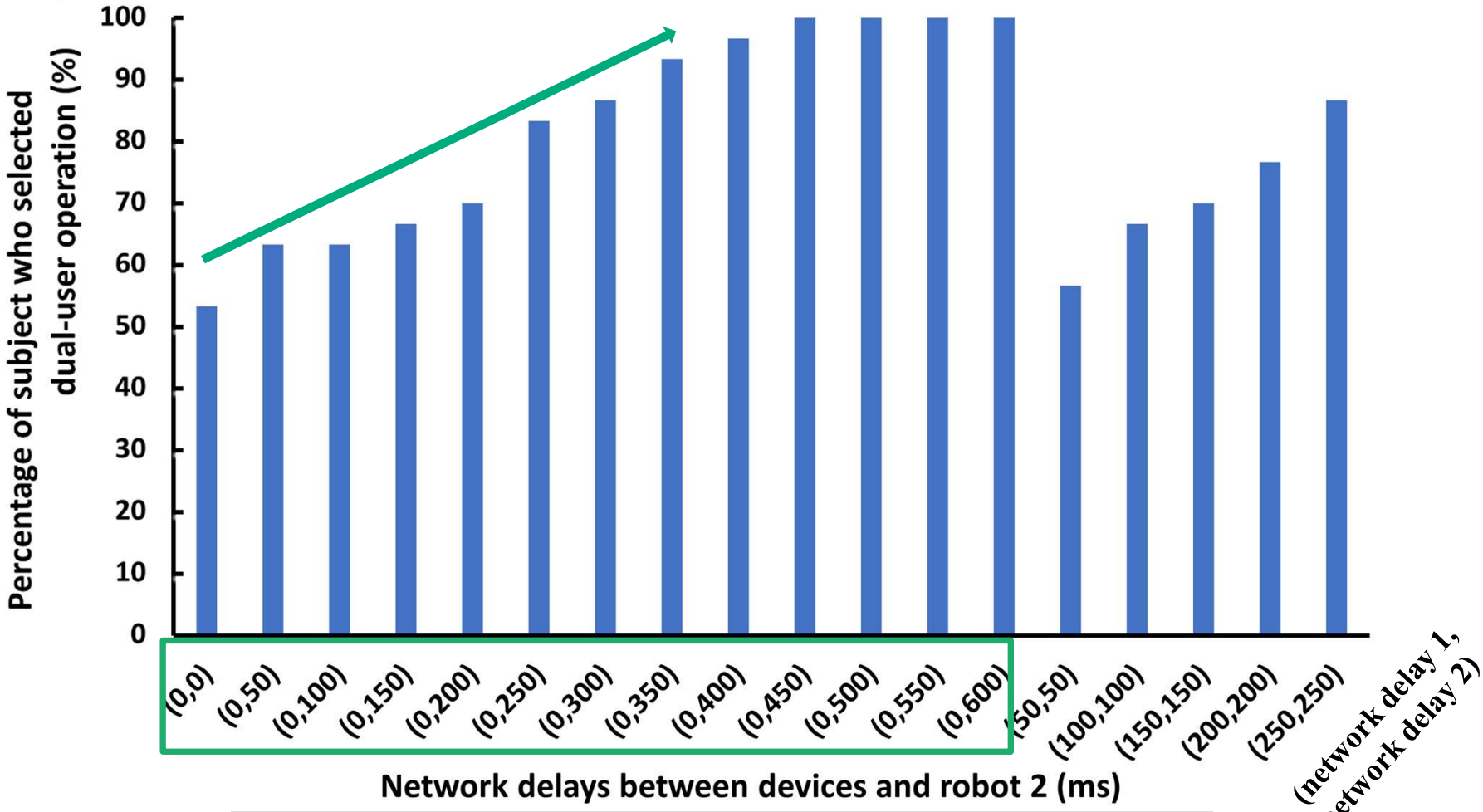
- Each subject made a comparison between single-user and dual-user operation subjectively under the condition that network delay 2 was the same.
- We presented combinations of both single-user and dual-user operations to the subject, the order of each operation was randomly selected.
- Network delays were presented in random order to the subject.
- Each subject was asked to answer which of the first or second was better than the other in terms of the operability of the haptic interface device.
- Number of subjects: 30 (ages between 23 and 30).

Assessment Results (1/2)



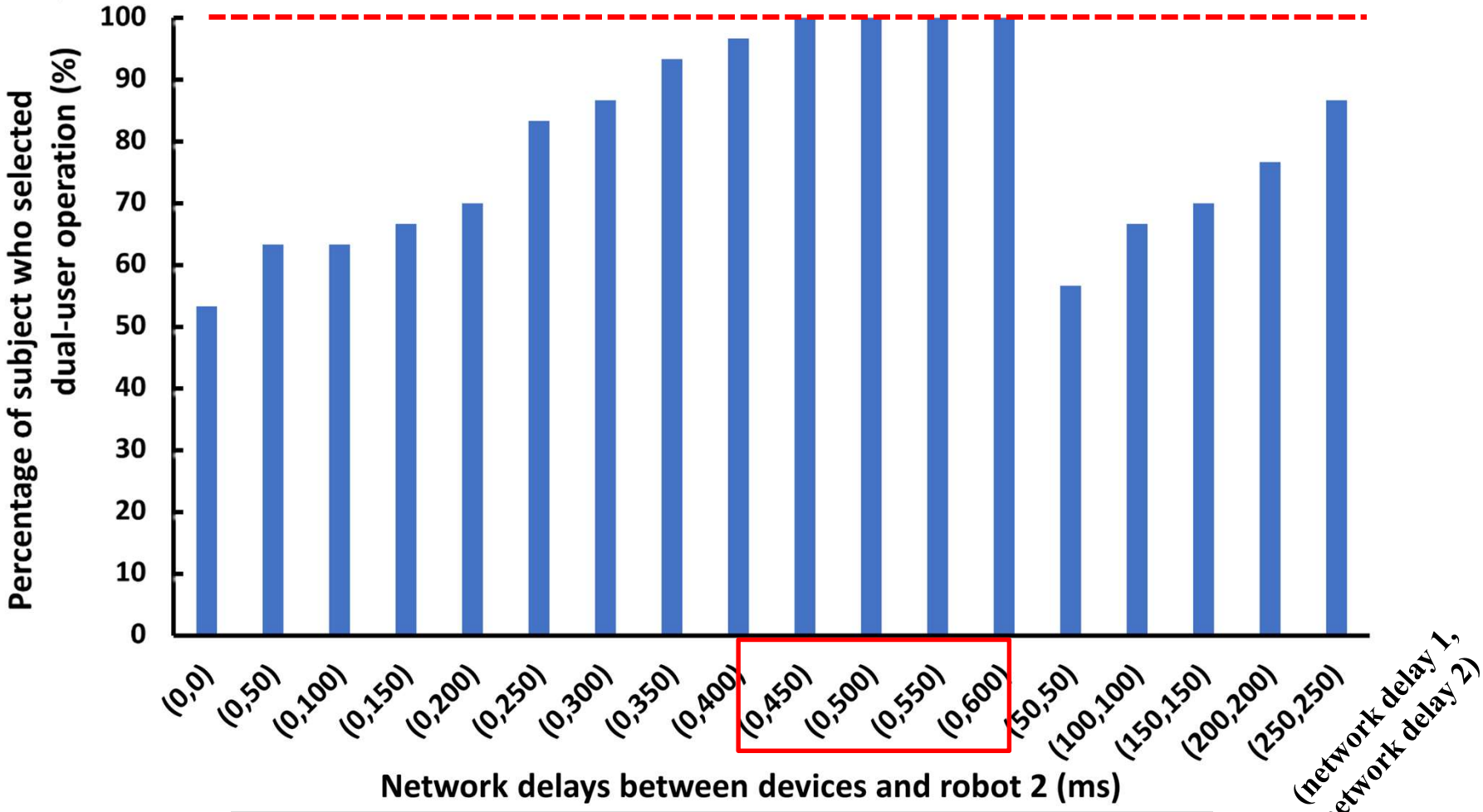
Percentage of subjects who selected dual-user operation for network delays between devices and robot 2

Assessment Results (1/2)



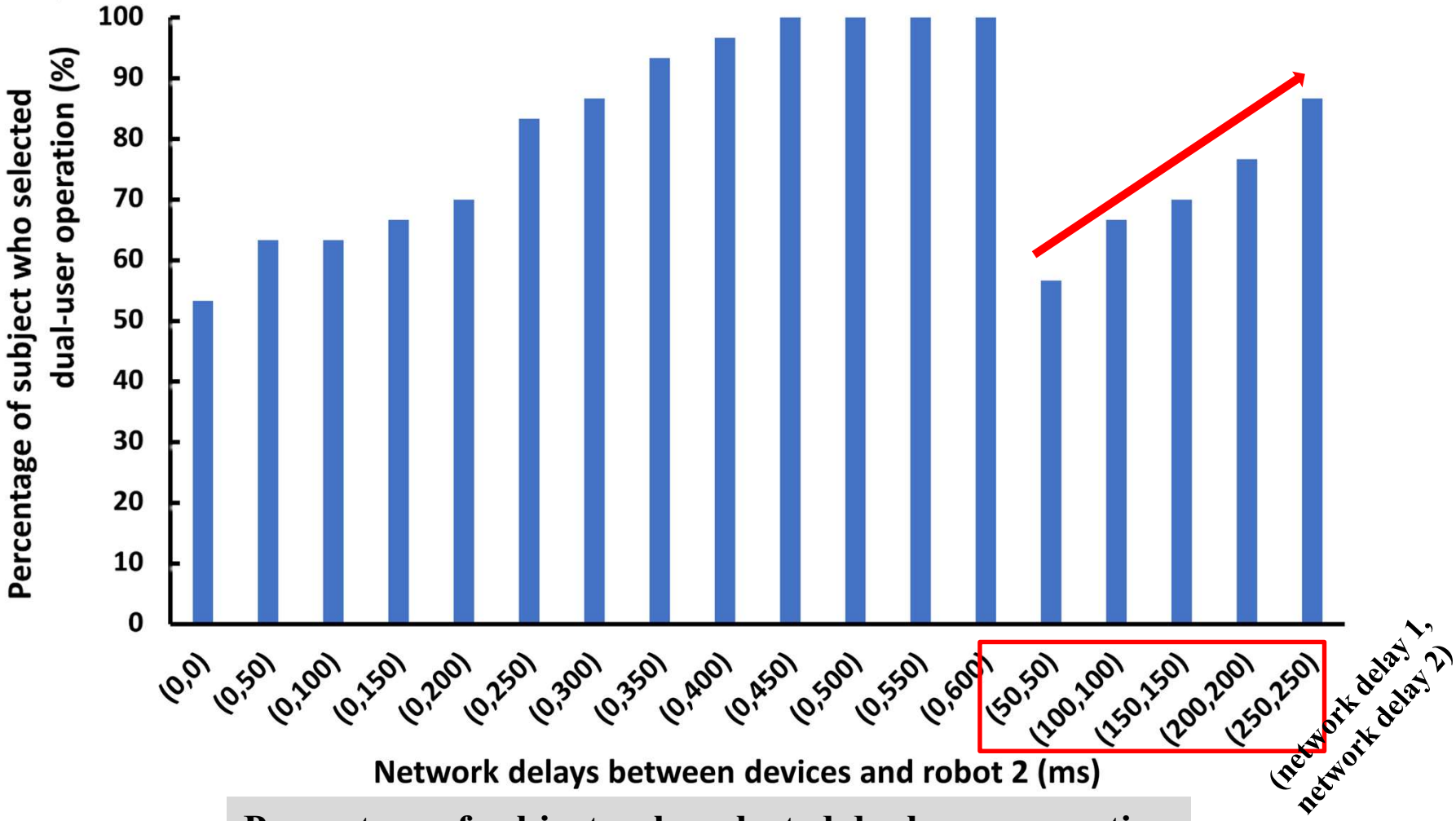
Percentage of subjects who selected dual-user operation for network delays between devices and robot 2

Assessment Results (1/2)



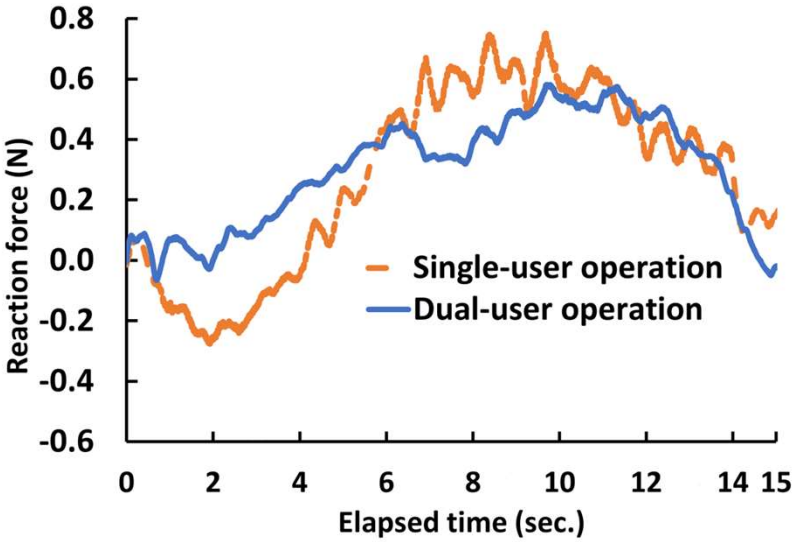
Percentage of subjects who selected dual-user operation for network delays between devices and robot 2

Assessment Results (1/2)

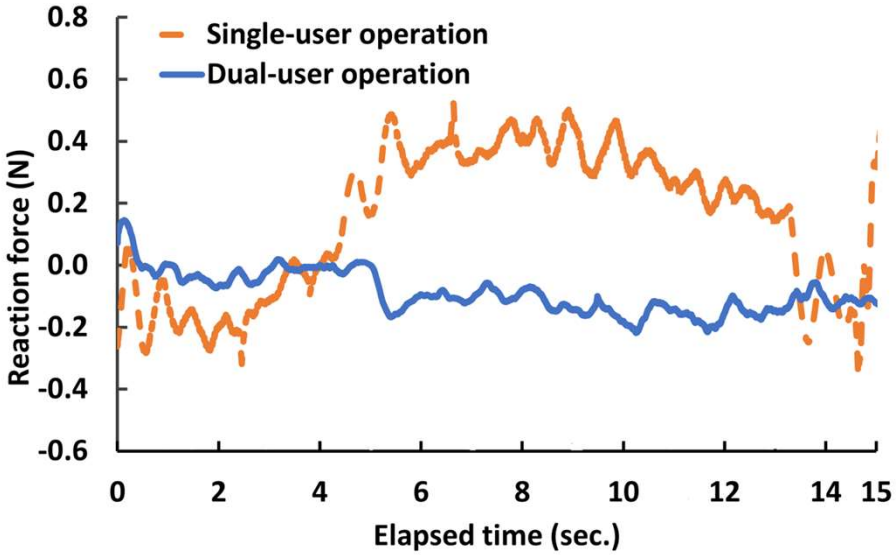


Percentage of subjects who selected dual-user operation for network delays between devices and robot 2

Assessment Results (2/2)



(a) (0,200)



(b) (200,200)

(Network delay 1, Network delay 2)

Reaction force versus Elapsed time

Conclusion and Future work

Conclusion

- **Examined how largely the dual-user operation is superior to the single-user operation in remote robot systems with force feedback.**

Found that as the network delay becomes larger, the dual-user operation is more largely superior to the single-user operation.

Future work

- **Investigate relationships between QoE assessment and objective assessment results such as the average force and position difference.**