Softness Comparison of Stabilization Control in Remote Robot System with Force Feedback

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Background (1/2)

- **Remote robot systems with force feedback have been actively researched.**

A user remotely controls a robot having force sensors by operating a haptic interface device.

- **It is possible to transmit the information about the shape, weight, and softness of a remote object by using the haptic interface device.**

The efficiency and accuracy of work can largely be improved.

Background (2/2)

When remote operation is performed over the Internet, which does not guarantee the QoS (quality of service)

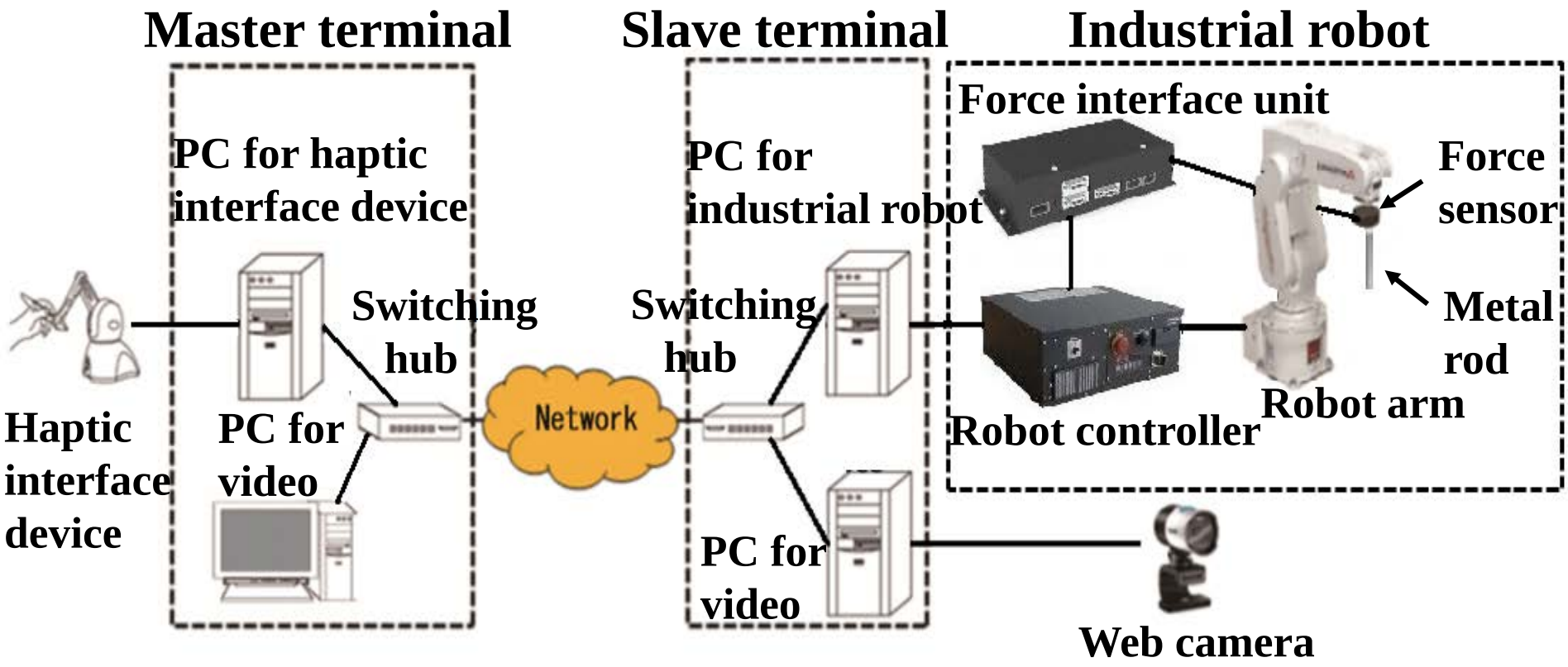
Network delay, delay jitter and packet loss

Instability phenomena

QoE (Quality of Experience) degradation

- **Stabilization control**
- **QoS control**

Remote Robot System with Force Feedback



*1 K. Suzuki *et al.*, Proc. IEEE GCCE, Oct. 2015.
*2 P. Huang *et al.*, IEICE, CQ2016-125, Mar. 2017.
*3 P. Huang *et al.*, IEICE, CQ2017-79, Nov. 2017.

Previous Work (1/3)

- **For stabilization, the stabilization control with filters [*1] was applied to the remote robot system with force feedback[*2].**

There was a problem of vibration for hard objects.

Another method [*3] was proposed to solve the vibration problem in the stabilization control with filters.

The vibration problem for hard objects was solved. However, the quality for soft objects is not good.

*4 T. Rikiishi *et al.*, IEICE Society Conference, BS-7-21, Sep. 2017.
*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

Previous Work (2/3)

- **To suppress instability phenomena, the stabilization control by viscosity [*4] was proposed.**

→ **Instability phenomena were solved for soft objects, but the robot arm jumped up when the arm hit a hard object.**

- **To prevent the robot arm from jumping up when the arm hit a hard object, the reaction force control upon hitting [*5] was proposed.**

→ **The control was effective for hard objects. However, the effect for soft objects is not clear.**

*6 Q. Qian *et al.*, IEICE Global Conference, BS-2-14, Mar. 2018.

Previous Work (3/3)

- **For combining the advantages of the stabilization control by viscosity and the reaction force control upon hitting, the switching control [*6] was proposed for the remote robot system with force feedback.**

- ✓ **The effect for soft objects in the switching control was almost the same as that in the stabilization control by viscosity.**
- ✓ **The effect for hard objects in the switching control was almost the same as that in the reaction force control upon hitting.**

*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

Problems

The four types of stabilization control have their own features.

Comparison

Clarify the applicability of each control to use them effectively

However, only a comparison between the reaction force control upon hitting and the stabilization control with filters has been carried out [*5].

*5 R. Arima *et al*., IEICE, CQ2017-98, Jan. 2018.

Purpose

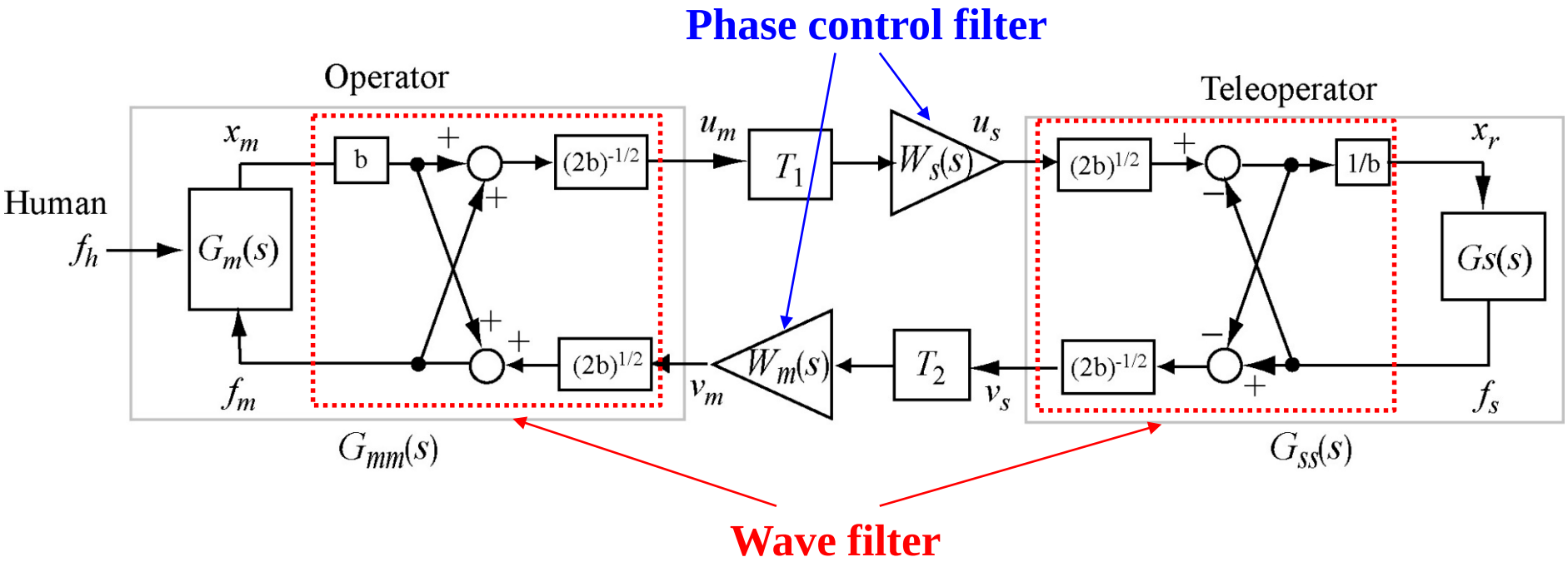
This work

- **We deal with the four types of stabilization control for the remote robot system with force feedback.**
- **We compare effects of the four types of stabilization control by carrying out QoE assessment.**

*3 P. Huang *et al.*, IEICE, CQ2017-79, Nov. 2017.
*7 T. Miyoshi *et al.*, Proc. IEEE CCA, pp. 1318-1324, Oct. 2006.
*8 M. D. Duong *et al.*, Proc. 17th IFAC World Congress, pp. 12715-12720, July 2008.

Stabilization Control with Filters *7, *8

- **The stabilization control with filters uses the wave filter in combination with the phase control filter.**
- **The control can make the remote robot system with force feedback stable against any network delay *3.**



*4 T. Rikiishi *et al.*, IEICE Society Conference, BS-7-21, Sep. 2017.

Stabilization Control by Viscosity*4

- **Viscosity is generated by decreasing the movement distance of the robot arm by a certain amount proportional to the movement velocity.**

- **The instability phenomenon was suppressed by restricting the movement distance of the robot arm.**

*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

Reaction Force Control upon Hitting*5

- **The reaction force outputted by the haptic interface device is gently increased when the reaction force increases rapidly.**

- **The robot arm would not jump up when the arm hit a hard object.**

*6 Q. Qian *et al.*, IEICE Global Conference, BS-2-14, Mar. 2018.

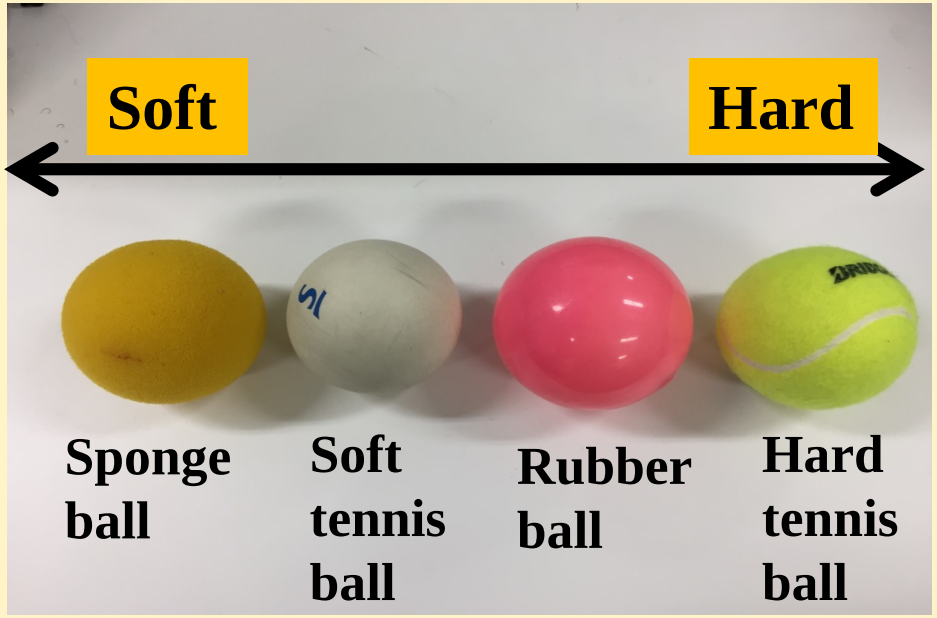
Switching Control*6

- **Behaving as the stabilization control by viscosity for soft objects and as the reaction force control upon hitting for hard objects.**

In a preliminary experiment, we found that the stabilization control by viscosity is effective for soft objects, and the reaction force control upon hitting is effective for hard objects.

Assessment Method (1/3)

- Each subject did work of pushing four balls with different softness by a metal rod attached to the tip of the robot arm.

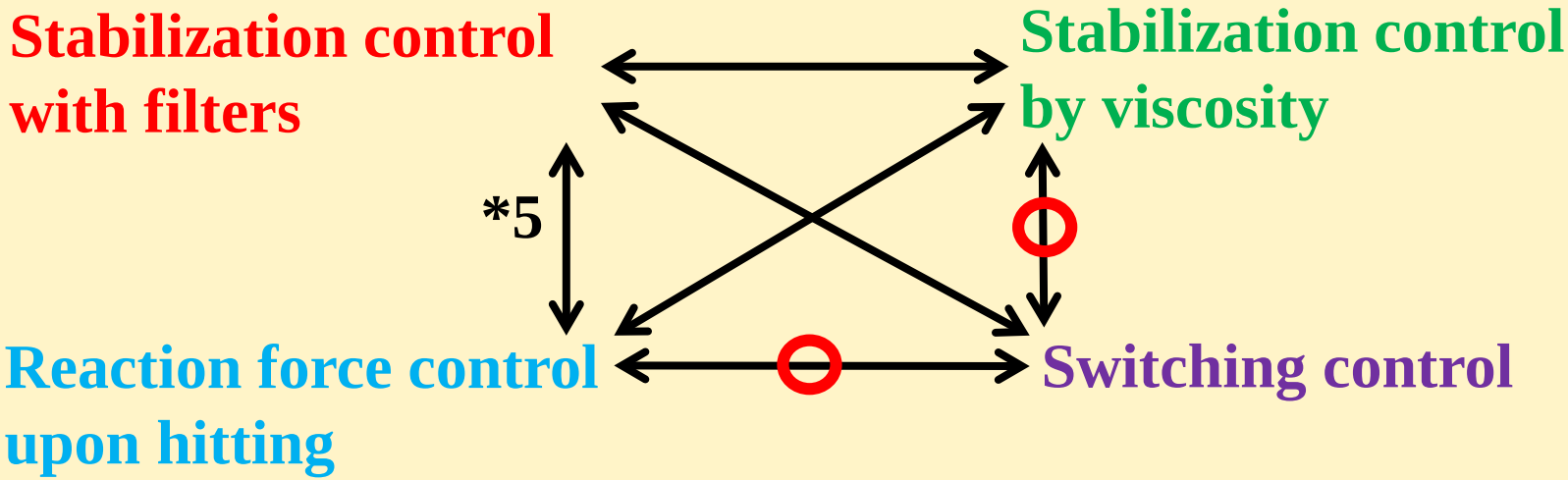


- There were 15 subjects whose ages were between 24 and 30.

*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

Assessment Method (2/3)

➢ **Four assessments of object softness**



***Switching control* behaves as the *stabilization control by viscosity* for soft objects and as the *reaction force control upon hitting* for hard objects.**

Assessment Method (3/3)

- **Presentation method of stimuli**

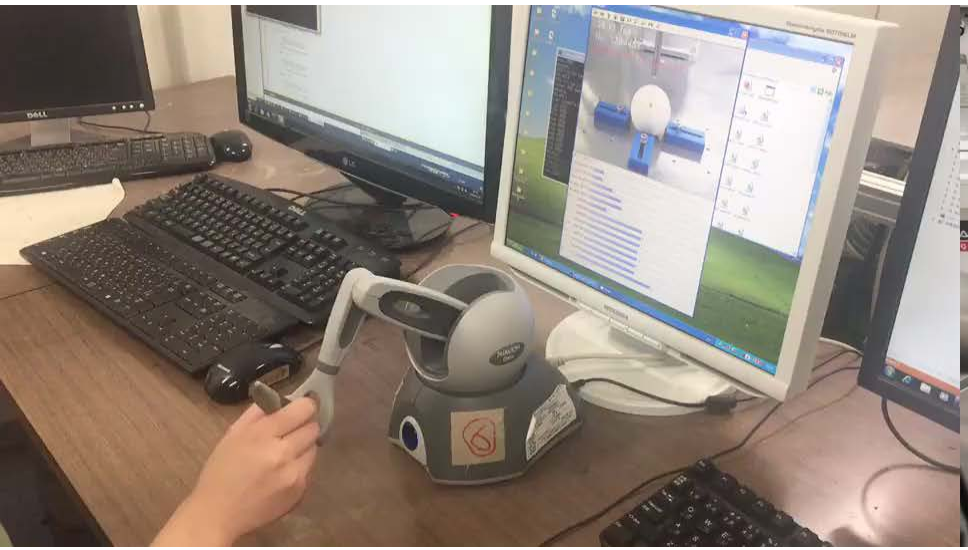
- **Two types of control were presented randomly to each subject for each combination in each assessment.**
- **network delay and ball were also presented randomly.**

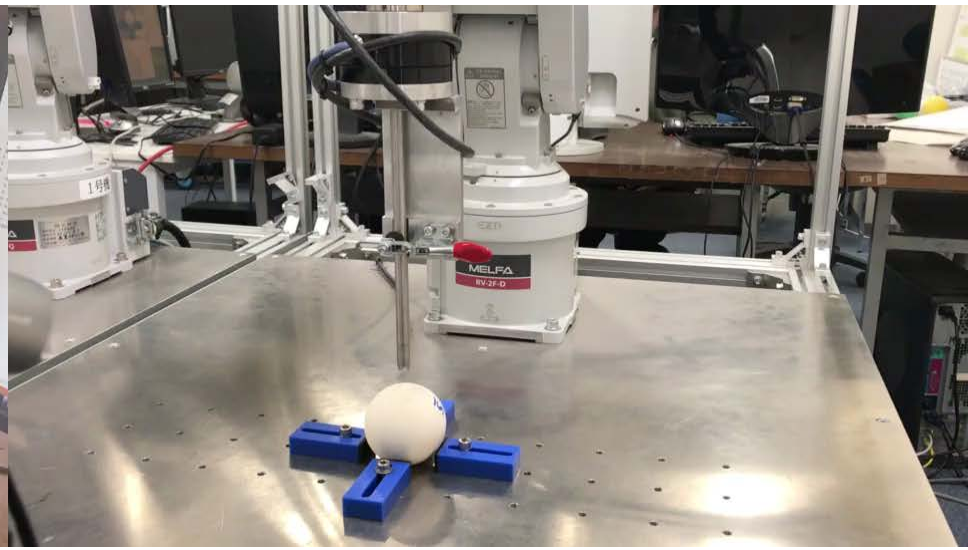
- **Answer method by subjects**

- **Each subject answered which control between the two types of control produced the closer feeling of pushing the ball with hand via the stylus of the haptic interface device.**

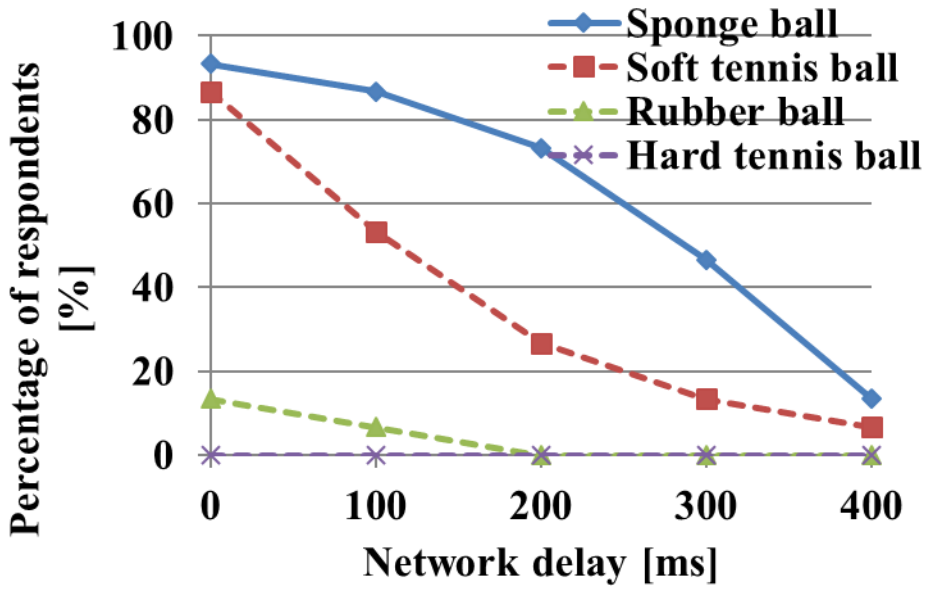
- **The subject selected one of the following three answers**
  1. **"The first type is closer than the second type."**
  2. **"The second type is closer than the first type."**
  3. **"The first type is almost the same as the second type."**

Demo video – Pushing Soft Tennis Ball

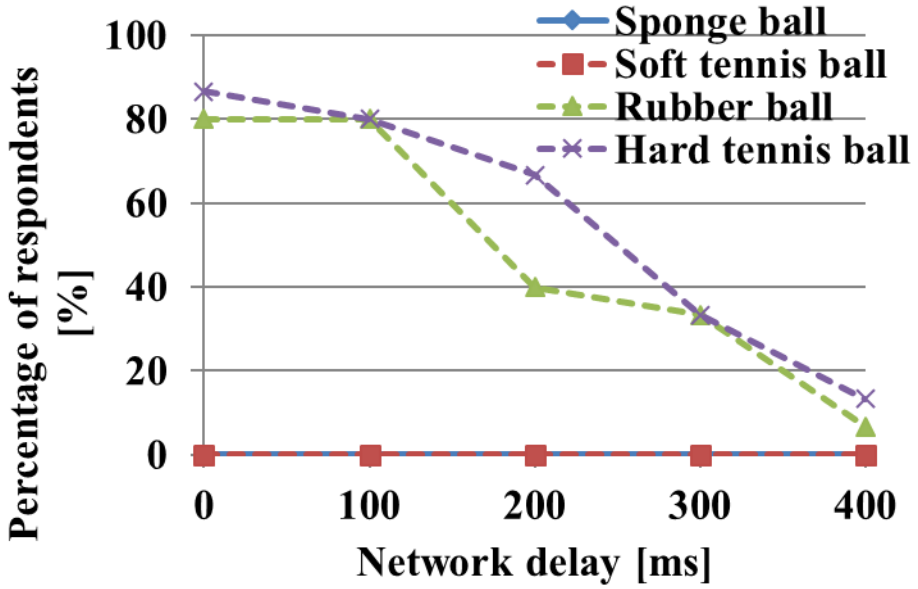




Assessment Results (1/4)



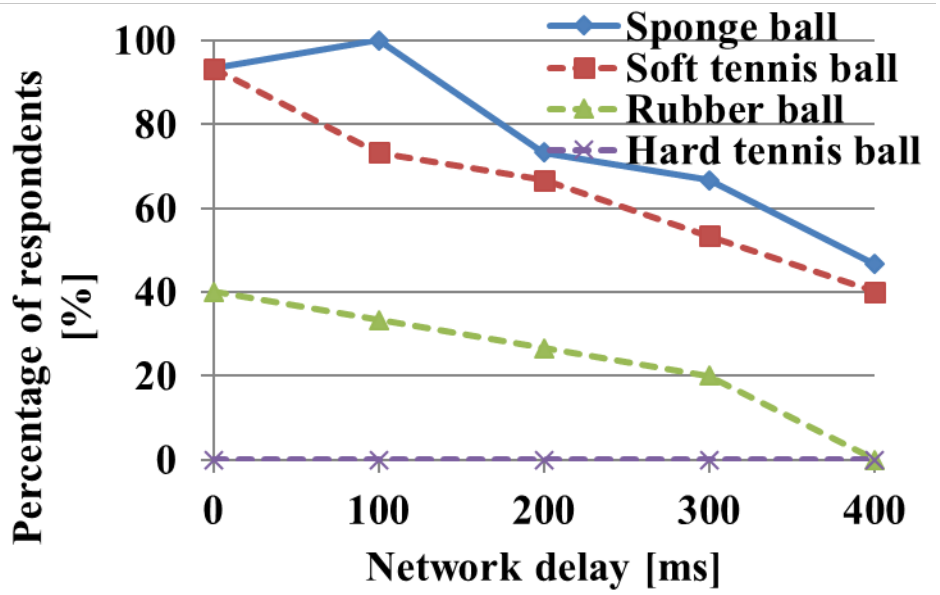
(a) Percentage of respondents who answered that stabilization control by viscosity is closer



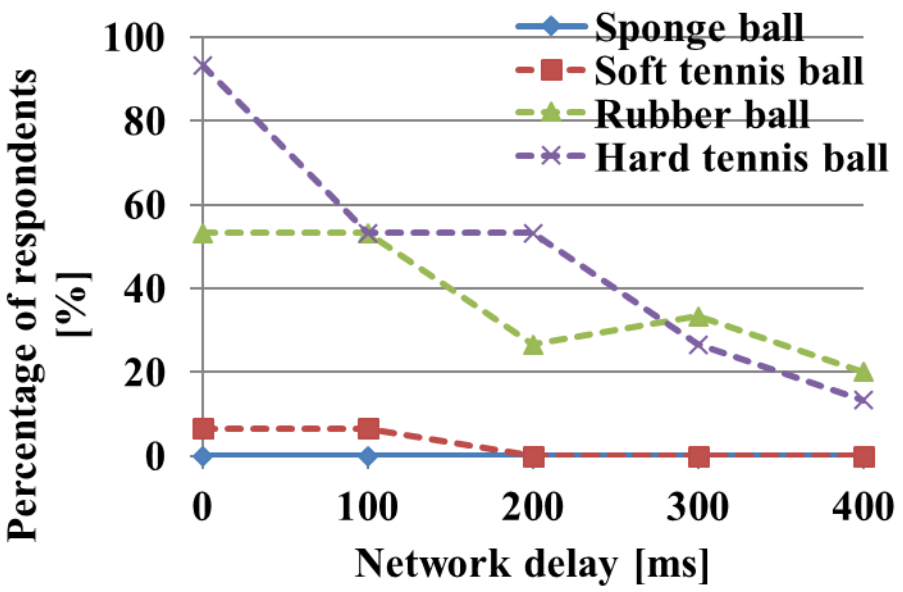
(b) Percentage of respondents who answered that stabilization control with filters is closer

Assessment between the stabilization control by viscosity and the stabilization control with filters

Assessment Results (2/4)



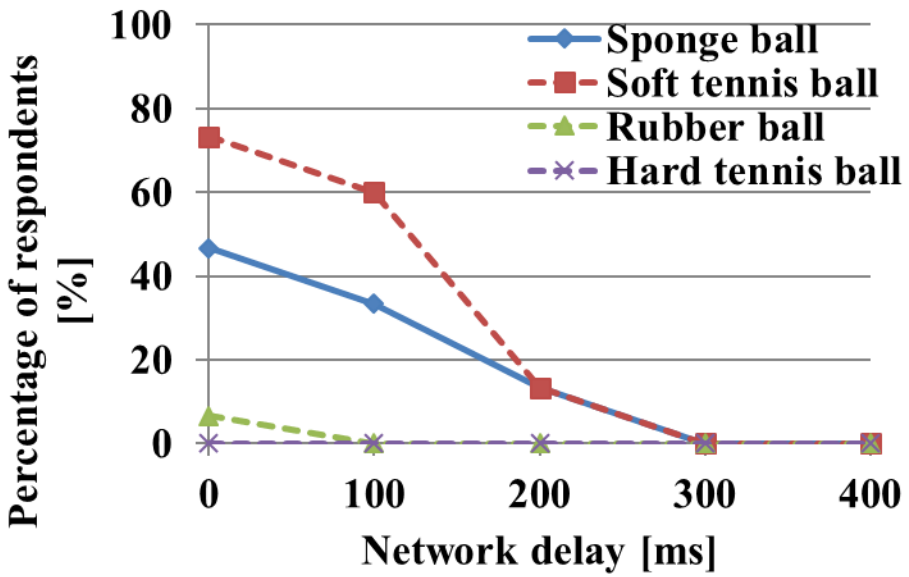
(a) Percentage of respondents who answered that switching control is closer



(b) Percentage of respondents who answered that stabilization control with filters is closer

Assessment between the switching control and the stabilization control with filters

Assessment Results (3/4)



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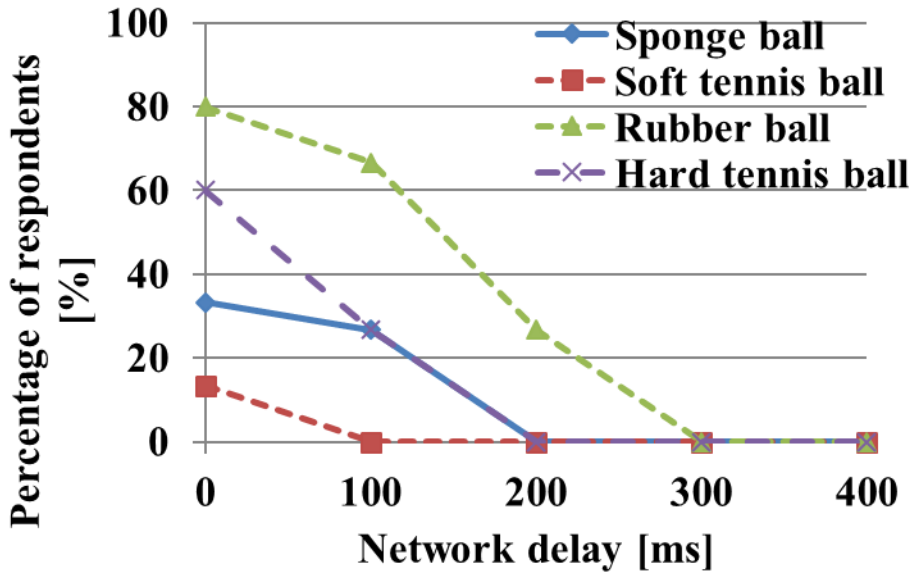
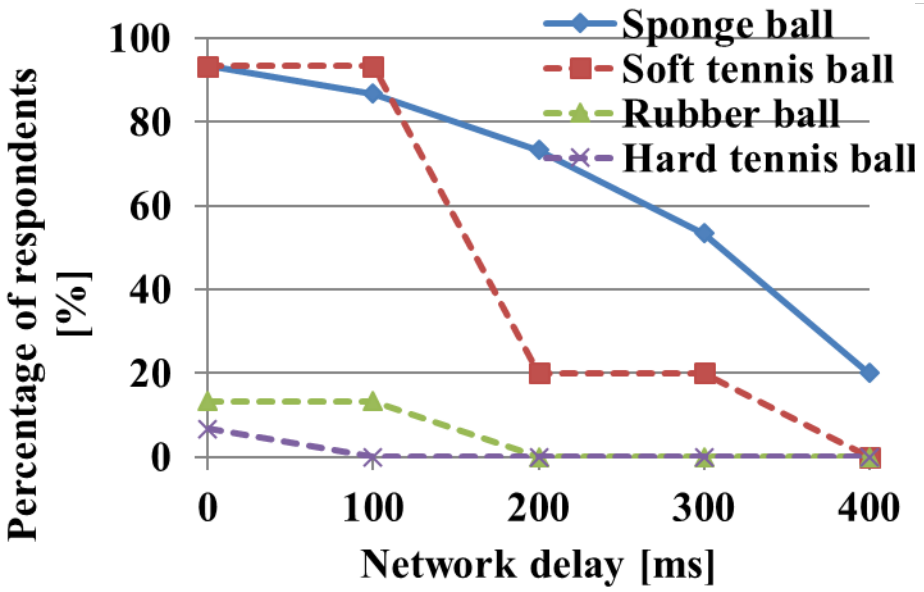


(b) Percentage of respondents who answered that reaction force control upon hitting is closer

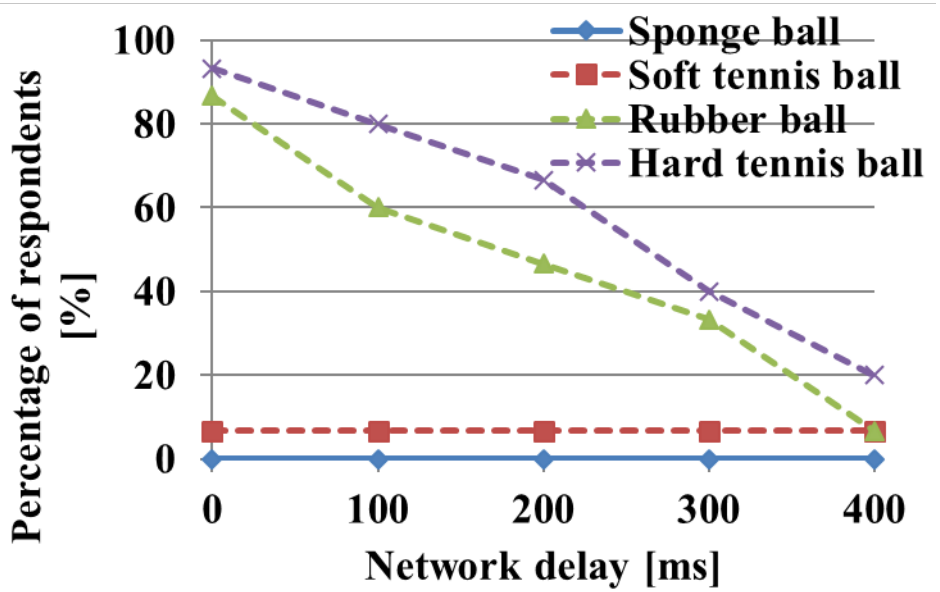
Assessment between the stabilization control by viscosity and the reaction force control upon hitting

*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

Assessment Results*5 (4/4)



(a) Percentage of respondents who answered that reaction force control upon hitting is closer



(b) Percentage of respondents who answered that stabilization control with filters is closer

Assessment between the reaction force control upon hitting and the stabilization control with filters

Summary of Comparison Results

Object	Effective stabilization control
Sponge ball	Viscosity/Switching
Soft tennis ball	Viscosity/Switching
Rubber ball	Filters
Hard tennis ball	Filters

Filters: Stabilization control with filters
Viscosity: Stabilization control by viscosity
Hitting: Reaction force control upon hitting
Switching: Switching control

*6 Q. Qian *et al.*, IEICE Global Conference, BS-2-14, Mar. 2018.

Conclusion

We investigated the effects of the four types of stabilization control on object softness for a remote robot system with force feedback by QoE assessment.

- ✓ **The effect for soft objects in the switching control was almost the same as that in the stabilization control by viscosity[*6].**
- ✓ **The effect for hard objects in the switching control was almost the same as that in the reaction force control upon hitting [*6].**

The switching control is the most effective among the four types of stabilization control for soft objects, and the stabilization control with filters is the most effective for hard objects.

Future Work

- **Improvement of the softness quality under the four types of control when the network delay is large**

- **Combination use of stabilization control and QoS control (e.g., error control, buffering control, and adaptive reaction force control)**