Effect of Stabilization Control on Cooperative Work between Remote Robot Systems with Force Feedback

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Remote robot systems with force feedback have been actively researched. Users remotely control robot arms having force sensors by using haptic interface devices.

Many researchers have paid attention to cooperative work among multiple remote robot systems recently.

It is possible for users to perceive the shape, weight, and softness of a remote object with force feedback.

The efficiency and accuracy of work are expected to be improved largely.
When force information is transmitted over the Internet, which does not guarantee the quality of service (QoS)

- Network delay, delay jitter and packet loss
- Quality of Experience (QoE) degradation
- Instability phenomena

- Stabilization control
- QoS control
Previous Work

• Influence of network delay on the efficiency of cooperative work between a user and a remote robot system with force feedback was investigated*1.
  ✔ The average time of work increases as the network delay becomes larger.

• The efficiency of cooperative work between two remote robot systems with force feedback was clarified*2.
• Comparison of the efficiency was made*2.
  ✔ The average times of the two types of work are roughly the same.
  ✔ The force between the systems is larger than that between the user and system.

Problem
Both experiments have instability phenomena when the network delay is large.
Purpose

This work

- We apply the switching control*3 as stabilization control to the remote robot system with force feedback.

- We investigate the effect of the switching control on hand delivery of an object between the two systems.

- We examine the influence of network delay on the hand delivery by experiment.

*3 Q. Qian et al., IEICE Global Conference, BS-2-14, Mar. 2018.
Remote Robot Systems with Force Feedback
Switching Control*3

• Carrying out the stabilization control by viscosity*4 for soft objects and the reaction force control upon hitting*5 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.

Judgement of Softness

If the increment of reaction force for an object exceeds a threshold, the object is judged as a hard object.
Stabilization Control by Viscosity

• The instability phenomenon can be suppressed by viscosity.

• We generate viscosity by decreasing the movement distance of the robot arm by a certain amount proportional to the position difference.

Reaction Force Control upon Hitting

• The reaction force outputted by the haptic interface device is gradually increased to avoid the jump-up of the robot arm when the arm hits hard objects.
Deal with two types of cooperative work (work A and work B) in which a wooden stick with lengths of 30 cm was hand-delivered between the two robot arms under the switching control and no stabilization control.

- **Work A (pass)**: Wooden stick
- **Work B (receive)**: Electric hand

**Experiment Method (1/2)**

Robot arm 2

(Fixed position) Robot arm 1

Robot arm 2

(Fixed position) Robot arm 1
Experiment Method (2/2)

- We produced the additional delay which was varied from 0 ms to 200 ms at intervals of 100 ms by using a network emulator.
- The additional delays for systems 1 and 2 were selected in random order.
- We carried out the experiments 10 times for each combination of additional delays in work A and work B.
- The average work time was measured
  - The average time from the moment the work is started until the instant the stick is hand-delivered.
- One of the authors operated robot arm 2, and another person did robot arm 1.
Demo video

Cooperative work: Work B (receive)
Additional delay: 0 ms
Stabilization control: Switching control
Experiment Results (1/2)

(a) No stabilization control

\[ K_{\text{scale}} = 0.2 \]

(b) Switching control

\[ K_{\text{scale}} = 0.2 \]

**Work B (receive)**

\[ K_{\text{scale}} \] :
Mapping ratio about scale of force between the haptic interface device and the robot arm.
Experiment Results (2/2)

**Work B (receive)**

- **Average work time [sec.]**
- **I: 95% confidence interval**
- **Additional delay in system 1 [ms]**
  - 0 ms
  - 100 ms
  - 200 ms

- **Additional delay in system 2 [ms]**
  - 0 ms
  - 100 ms
  - 200 ms
We investigated the effect of the switching control on hand delivery of an object between the two remote robot systems with force feedback by experiment. We also examined the influence of the network delay on the hand delivery of the object.

The switching control is effective for the cooperative work. The average work time increases as the network delay becomes larger.
Future Work

- Study of QoS control to reduce the average work time\(^6\)
- Dealing with other types of cooperative work under the switching control