Effect of Stabilization Control on Hand Delivery of Object between Remote Robot Systems with Force Feedback

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Background (1/2)

- 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), several issues arise:

- Network delay, delay jitter, and packet loss

These phenomena lead to:

- Quality of Experience (QoE) degradation
- Instability phenomena

To mitigate these issues, the following strategies are employed:

- 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.

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

**Calculation for position of robot arm**

\[
S_t = M_{t-1} \quad \rightarrow \quad S_t = M_{t-1} - C_d(M_{t-1} - S_{t-1})
\]

- **\(S_t\)**: Position vector of robot arm at time \(t\) \((\geq 1)\)
- **\(M_t\)**: Position vector of haptic interface device at time \(t\) \((\geq 1)\)
- **\(C_d\)**: Coefficient related to viscosity
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.

\[
F_{t}^{(m)} = K_{\text{scale}} F_{t-1}^{(s)}
\]

\[
F_{t}^{(m)} = \begin{cases} 
K_{\text{scale}} (F_{t-1}^{(m)} + K_{i} F_{\text{th}}) & (|F_{t-1}^{(m)} - K_{\text{scale}} F_{t-1}^{(s)}| > |F_{\text{th}}|) \\
K_{\text{scale}} F_{t-1}^{(s)} & \text{(otherwise)}
\end{cases}
\]

- \(F_{t}^{(m)}\): Reaction force outputted at time \(t \geq 1\)
- \(|F_{\text{th}}|\): Threshold (0.003 N/ms)
- \(F_{t}^{(s)}\): Force received from slave terminal at time \(t \geq 1\)
- \(K_{\text{scale}}\): Mapping ratio about scale of force between the haptic interface device and the robot arm
- \(K_{i}\): Increment rate of force, \(K_{i} = 1.000 + 0.001i \quad (i \geq 0)\)
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.
The mapping ratio about scale of work space between the haptic interface device and the robot arm was set to 1:1.

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.
Experiment Method (3/3)

- 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.
Experiment Results (1/4)

(a) No stabilization control

(b) Switching control

$K_{\text{scale}} = 0.2$

Elapsed time [sec.]

Force [N]
Demo video (1/2)

Cooperative work: Work A (pass)
Additional delay: 0 ms
Stabilization control: Switching control
Demo video (2/2)

Cooperative work: Work B (receive)
Additional delay: 0 ms
Stabilization control: Switching control
Experiment Results (2/4)

I: 95% confidence interval

Additional delay in system 1
- 0 ms
- 100 ms
- 200 ms

Average work time [sec.]

Additional delay in system 2
- 0 ms
- 100 ms
- 200 ms

Average work time [sec.]

Work A (pass)
Experiment Results (3/4)

I: 95% confidence interval

Additional delay in system 1

- 0 ms
- 100 ms
- 200 ms

Additional delay in system 2

- 0 ms
- 100 ms
- 200 ms

Average work time [sec.]

Work B (receive)
Experiment Results (4/4)

I: 95% confidence interval

![Graph showing the relationship between average work time and additional delays in systems 1 and 2. The graph compares two works: Work A (blue line) and Work B (red line). The x-axis represents additional delays in milliseconds, ranging from 0 to 200, and the y-axis represents average work time in seconds, ranging from 0 to 10. The graph includes error bars indicating the 95% confidence interval.](image-url)
Conclusion

- 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

Work A (pass)

Robot arm 1

Robot arm 2
Work B (receive)

Robot arm 1

Robot arm 2