Effect of QoS Control for Cooperative Work between Remote Robot Systems with Force Feedback

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Remote robot systems with force feedback have actively been researched.

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

The efficiency and accuracy of work can largely be improved by using the remote robot system with force feedback.

When we transmit haptic information over the Internet, which does not guarantee QoS (Quality of Service), network delay, delay jitter, and packet loss occur. QoE (Quality of Experience) degrades, and instability phenomena occur.

QoS control and stabilization control.
Previous work*1

- Performed the collaborative work by using the two remote robot systems and the adaptive $\Delta$-causality control as QoS control and Stabilization control with filter.
- By the adaptive $\Delta$-causality control, we can adjust the output timing of position information between terminals according to the network delay.
- The influence of network delay can greatly be alleviated.
- Large force is applied to the object when changing the movement direction.

- This problem may be solved by applying the robot position control using force information*2 as QoS control to the system.

Purpose

This work

✓ We apply the robot position control using force information to the systems where the adaptive Δ-causality control and the stabilization control are carried out.

✓ Investigate the effect of the robot position control using force information by experiment
Remote robot systems with force feedback

System 1
- Master terminal PC for video
- Slave terminal PC for video
- Master terminal PC for video
- Slave terminal PC for video
- Web camera
- Industrial robot
- Switching hub
- PC for haptic interface device
- Force interface unit
- Robot controller
- Force sensor
- Toggle clamp hand
- Robot arm
- PC for haptic interface device
- PC for industrial robot
- PC for industrial robot and video
- Force interface unit
- Robot controller

System 2
- Master terminal PC for video
- Slave terminal PC for video
- Master terminal PC for video
- Slave terminal PC for video
- Web camera
- Industrial robot
- Switching hub
- PC for haptic interface device
- Force interface unit
- Robot controller
- Force sensor
- Toggle clamp hand
- Robot arm
- PC for haptic interface device
- PC for industrial robot
- PC for industrial robot and video
- Force interface unit
- Robot controller
Calculation method of force

**Force outputted at master terminal**

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

\( F_{t}^{(m)} \): Reaction force outputted at the master terminal at time \( t (>0) \)

\( F_{t}^{(s)} \): Force received at the master terminal from the slave terminal at time \( t (> 0) \)

\( K_{\text{scale}} \): Force scale which changes \( F_{t-1}^{(s)} \)

\[ K_{\text{scale}} = 0.5^{*1} \]

Calculation method of position

**Position of robot**

\[ S_t = \begin{cases} \mathbf{M}_{t-1} + \mathbf{V}_{t-1} & (|\mathbf{V}_{t-1}| \leq V_{\text{max}}) \\ \mathbf{M}_{t-1} + V_{\text{max}} \frac{\mathbf{V}_{t-1}}{|\mathbf{V}_{t-1}|} & \text{(otherwise)} \end{cases} \]

- \( S_t \) : Position vector of industrial robot at time \( t \) (\( t > 1 \))
- \( \mathbf{M}_t \) : Position vector of haptic interface device at time \( t \)
- \( \mathbf{V}_t \) : Velocity vector of industrial robot
- \( V_{\text{max}} \) : Maximum velocity of industrial robot (5 mm/ms)
Carrying object together

- Move a wooden stick together by the two industrial robot arms while watching video.
- In order to move the robot arms in almost the same way always, we push and drop the uppermost block of the piled building blocks by moving the robot arms together with the force feedback devices.
Demo video

Additional delay : 0 ms
Cooperation method between systems

✓ The position information of the robot arm at each system is transmitted to the other system.

✓ The robot arm whose operation timing is delayed is controlled by using the information.
No QoS Control

Robot arm’s motion is delayed by $\Delta$ ms.

Large network delay : $\Delta$ ms

Send position information

Output position information

Large force may be applied to an object.
Adaptive $\Delta$-causality control (1/2)

Network delay: $\Delta$ ms

Wait for $\Delta$ ms without output

Send position information

Output position information

Robot arm’s motion is not delayed.

No large force can be applied to an object.
Δ is set to the smoothed network delay.

\[
\begin{align*}
\Delta &= d_0 \\
\Delta &= \alpha\Delta + (1 - \alpha)d_t & (t \geq 1)
\end{align*}
\]

Smoothing coefficient \(\alpha = 0.998\)

\(d_t\) : Network delay at time \(t\)

Information received after generation time + Δ is discarded as old and useless information.

Stabilization control with filters

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*4.

The robot position control using force information finely adjusts the robot position in order to reduce the force applied to the object.

\[ \vec{S}_t = S_t + P \]

- \( \vec{S}_t \): Position vector of robot arm after adjustment at time \( t (> 0) \)
- \( S_t \): Position vector of robot arm before adjustment at time \( t (> 0) \)
- \( P \): Position adjustment vector
The force applied to a wooden stick is measured by gripping both ends of the wooden stick with the two robot arms and moving one robot arm for a certain distance\(^5\).

\[ P_x = a_x F_x \]

- \( P_x \): Movement distance of the robot arm at \( x \) axis
- \( F_x \): Force vector sensed by force sensor at \( x \) axis
- \( a_x \): Function of length \( l \) of the wooden stick\(^2\)

\[ a_x = 4.82 \times 10^{-2}l - 1.16 \]

We can calculate the difference in the position vector between the two robot arms from the force applied to the stick with length of \( l[\text{cm}] \)\(^2\).
Experiment method

- We generated a constant delay (called the *additional delay*) for each packet transmitted between the two systems by a network emulator.

- We changed the additional delay between the two systems from 0 ms to 400 ms at intervals of 100 ms.

- We performed each task 10 times with and without the robot position control using force information.

- We measured the force sensed by the force sensor.
Experimental results (1/2)

Average maximum force of system 1

- Without control
- With control

I: 95% confidence interval
Experimental results (2/2)

Additional delay: 400 ms

No robot position control

Robot position control
We examined the effect of the robot position control using force information for cooperative work in the remote robot systems with force feedback where the adaptive $\Delta$-causality control and the stabilization control are carried out.

We found that the robot position control using force information reduces the force applied to the object when the moving direction is reversed.
Future work

✓ We will further improve the stability of the systems.

✓ We will further reduce the force applied to the object.