Comparison of Stabilization Control for Writing Characters in Remote Robot System with Force Feedback

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Outline

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• Previous Work
• Purpose
• Remote Robot System with Force Feedback
• Calculation of Reaction Force and Position
• Experiment Method
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• Conclusion and Future Work
Remote robot systems with force feedback have been actively researched.

It is possible for users to perceive shapes, weights, and softness of remote objects hit/touched by robot arm through a haptic interface device (i.e., force feedback).

The efficiency and accuracy of operations through a robot are expected to be improved largely.
Background (2/2)

When force information is transmitted over the Internet, which does not guarantee QoS (Quality of Service)

- Network delay, delay jitter, and packet loss

QoE (Quality of Experience) degradation

Instability phenomena occur

- Stabilization control
- QoS control
• Investigated the effect of the stabilization control with filters by experiment in which a user pushes a soft object with a robot arm*1.

The control can stabilize the remote robot operation without large dependence on the network delay and delay jitter.

• Proposed the stabilization control by viscosity and investigate the effect of the proposed control*2.

The stabilization control by viscosity can suppress instability phenomena.
Previous Work (2/3)

- Proposed **the reaction force control upon hitting** and compared the proposed control with stabilization control with filters*3.

  Clarified which domains (e.g., types of work) the proposed control is applied to effectively.

- Made a comparison among the previous three types of stabilization control and the switching control by pushing objects (balls) with different softness by a metal rod attached to the robot arm*4.

  The switching control is the most effective for soft objects, and the stabilization control with filters is the best for hard objects.

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Cooperative work of carrying an object together between two robots is handled, and the previous three types of stabilization control are compared by experiment*5.

The stabilization control with filters is the most effective.

The best stabilization control depends on types of work.

Purpose

This work

- Examine effects of the three types of control by writing characters.
  
  Easy for confirmation

- Make a comparison among the three to obtain the best stabilization control.

- Examine the influences of network delay on writing characters.
Remote Robot System with Force Feedback

Diagram:
- **Master terminal**: PC for haptic interface device, Switching hub, Haptic interface device.
- **Slave terminal**: PC for industrial robot, Switching hub, PC for video, Network.
- **Industrial robot**: Force interface unit, Robot controller, Robot arm, Force sensor, Toggle clamp hand, Web camera.
Calculation of Reaction Force


**Reaction Force Outputted at Master Terminal**

\[
F_t^{(m)} = K_{scale}^{(F)} F_t^{(s)} - 1
\]

- \(F_t^{(m)}\): Reaction force outputted at master terminal at time \(t\) (\(t \geq 1\))
- \(F_t^{(s)}\): Force received from slave terminal at time \(t\)
- \(K_{scale}^{(F)}\): Mapping scale about force between industrial robot and haptic interface device

\((K_{scale}^{(F)} = 0.25 \ast 6)\)
Calculation of Position

Position of Robot

\[ S_t = K_{scale}^{(S)} M_{t-1} \]

- \( S_t \): Position vector of industrial robot at time \( t \) (\( t \geq 1 \))
- \( M_t \): Position vector of haptic interface device at time \( t \)
- \( K_{scale}^{(S)} \): Mapping scale about work space
Experiment Method (1/3)

- Two types of work (writing with pen and without pen *6 at the haptic interface device, robot always has pen)
- Two different pens (ink brush and ballpoint pen)
- Three different types of stabilization control
  - Reaction force control upon hitting
  - Stabilization control by viscosity
  - Stabilization control with filters
  - No control

Experiment Method (2/3)

Demo video (without ink brush, $K_{\text{scale}}^{(S)} = 1/2$)
• Wrote the character “永”.
• Produced a constant delay (called the *additional delay*) for each packet transmitted between the master and slave terminal.
• Examined the influence of character size by changing the value of $K_{\text{scale}}^{(S)}$.
• Compared among the three types of stabilization control.
• Investigated the influence of the network delay under the best stabilization control.
Experimental Results (1/3)

<table>
<thead>
<tr>
<th>Scales</th>
<th>Results without ink brush</th>
<th>Results with ink brush</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>No Error</td>
<td>No Error</td>
</tr>
<tr>
<td>3/2</td>
<td>Hitting Error</td>
<td>Hitting Error</td>
</tr>
<tr>
<td>1</td>
<td>Viscosity Error</td>
<td>Viscosity Error</td>
</tr>
<tr>
<td>1/2</td>
<td>Filters Error</td>
<td>Filters Error</td>
</tr>
<tr>
<td>1/4</td>
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<tr>
<td>1/6</td>
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<tr>
<td>1/8</td>
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</tbody>
</table>

The reaction force control upon hitting is the most effective.

- No control
- Reaction force control upon hitting
- Stabilization control by viscosity
- Stabilization control with filters

Additional delay=0 ms

Max and Min Error

<table>
<thead>
<tr>
<th>Error</th>
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</tbody>
</table>
Experimental Results (2/3)

Results of reaction force control upon hitting (best)

Different additional delays and scales

<table>
<thead>
<tr>
<th>Additional delays</th>
<th>Without ink brush</th>
<th>With ink brush</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ms</td>
<td>Max:2  Min1/6</td>
<td>Max:2  Min1/6</td>
</tr>
<tr>
<td>100 ms</td>
<td>永 永 永 永</td>
<td>永 永 永 永</td>
</tr>
<tr>
<td>300 ms</td>
<td>永 永 永 永</td>
<td>永 永 永 永</td>
</tr>
<tr>
<td>500 ms</td>
<td>永 永 永 永</td>
<td>永 永 永 永</td>
</tr>
</tbody>
</table>

As the additional delay increased:
- Characters became worse
- Operation becomes more difficult.
Conclusion

• We investigated the effects of the three types of stabilization control in the remote robot system and made a comparison among them.
• We examined the influence of the network delay.

➢ The reaction force control upon hitting is the most effective.
➢ The operation becomes more difficult as the network delay increases.

Future Work

• Deal with other types of cooperative work under the stabilization control.