Effect of Neural Network on Robot Position Control Using Force Information

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Outline

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- Remote Robot System with Force Feedback
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Remote robot systems with force feedback have actively been researched.

We can feel the shape, softness, surface smoothness, and weight of a remote object touched/hit by a remote robot with a force sensor through a haptic interface device (i.e., force feedback).

The efficiency and accuracy of work can largely be improved.
When the force information is transferred over the Internet, which does not guarantee the Quality of Service (QoS).

- Quality of Experience (QoE) Degradation
- Instability phenomena occur

Network delay, delay jitter and packet loss

• QoS control
• Stabilization control

In order to enhance the efficiency of QoS control,

We use big data, cloud computing, and AI (Artificial Intelligence) technologies.
Previous Work (1/2)

- Two remote robot systems with force feedback are used to handle cooperative work of moving an object together.
- The robot position control using force information as QoS control is applied to the systems *1.
- Examined the effectiveness of the control by experiment.

- The control is effective.
- There is the optimal value for position adjustment according to the force and the length of the object.
- The optimal value is also dependent on the material of the object.
Previous Work (2/2)

- They apply the big data, cloud computing, and AI technologies to the robot position control using force information as QoS control for the remote robot systems with force feedback.*
- The optimal model of the neural network is investigated, and the effect of the model is examined by simulation.*

- The technologies are effective.
- The optimal model of the neural network is three layers.
- The numbers of neurons in the input layer, hidden layer, and output layer are set to 2, 25, and 1, respectively.


It is important to investigate the effect of the model by experiment but it has not been carried out.
Purpose

This work

- We implement the neural network model for the robot position control using force information in the remote robot systems with force feedback.

- We examine the effect of the model by experiment.
Remote Robot System with Force Feedback

We use the two systems (called System 1 and System 2) in our experiment.
Reaction force outputted at master terminal

\[ F_t^{(m)} = K_{\text{scale}} F_{t-1}^{(S)} \]  \hspace{1cm} (1)

- \( F_t^{(m)} \): Reaction force is output at master terminal at time \( t (>0) \)
- \( F_t^{(S)} \): Force received from slave terminal at time \( t \)
- \( K_{\text{scale}} \): Coefficient (0.33*1) multiplied to force received from slave terminal
\[
S_t = \begin{cases} 
    M_{t-1} + V_{t-1} & \text{(if } |V_{t-1}| \leq V_{\text{max}}) \\
    M_{t-1} + V_{\text{max}} \frac{V_{t-1}}{|V_{t-1}|} & \text{(otherwise)}
\end{cases}
\] (2)

\(S_t\): Position vector of robot arm at time \(t > 0\)

\(M_t\): Position vector of haptic interface device received by slave terminal from master terminal at time \(t\)

\(V_t\): Velocity of robot arm at time \(t\)

\(V_{\text{max}}\): Maximum movement velocity (5mm/ms*4) of robot arm

The robot position control using force information finely adjusts the robot position to reduce the force applied to the wooden stick which we use as an object in experiment.

- The adjusted position vector $\hat{S}_t$ of the robot arm at time $t (> 0)$ is obtained by the following equation.

$$\hat{S}_t = S_t + P \quad (3)$$

$S_t$: Position vector obtained by Eq. (2)

$P$: Position adjustment vector
Robot Position Control Using Force Information (2/2)

Calculation method of $P_x^{*1}$ (x-axis of $P$)

$$P_x = a_x F_x \quad (4)$$

$a_x$: Function of the wooden stick length $L^{*1}$

$F_x$: Force in x-axis

$$a_x = 4.82 \times 10^{-2} l_{opt} - 1.16 \quad (5)$$

$l_{opt}$: Optimal value for $P_x$

Neural Network Model

We use python language and Keras library to implement the three-layer neural network model.
# Experiment Environment

## Neural Network Setting

<table>
<thead>
<tr>
<th></th>
<th>$F_x$ (N)</th>
<th>$L$ (cm)</th>
<th>$l_{opt}$ (cm)</th>
<th>$P_x$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Training data</strong></td>
<td>-6 ~ 6</td>
<td>30</td>
<td>55</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>76</td>
<td>Calculated by Equations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td><strong>Validation data</strong></td>
<td></td>
<td>25, 35, 45</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Experiment Method (1/3)

To examine the effect, we compare the experimental results when the wooden stick length $L$ are 25 cm, 35 cm, and 45 cm in the following cases.

- **Neural network control (NN)**
- **Equations: Calculate by Equations of robot position control using force information**
- **No control (NC)**

In the case where we use Equations, we use the optimal value of the similar length of the wooden stick which we had gotten.

<table>
<thead>
<tr>
<th>Length of wooden stick $L$ (cm)</th>
<th>25</th>
<th>35</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar length $L$ (cm)</td>
<td>30</td>
<td>30,40</td>
<td>40,60</td>
</tr>
</tbody>
</table>
The robot arm of system 1 is operated automatically at a constant velocity, and the robot arm of system 2 is operated manually with haptic interface device.
The operation was performed 10 times for each case.

Performance measure:

- **Average of average force**: the averages of the average forces applied to the wooden stick during the 10 operations.

- **Average of maximum force**: the averages of the maximum forces applied to the wooden stick during the 10 operations.
Experimental Results (1/3)

(a) Average of average force

Length: 25 cm
I: 95% confidence interval

<table>
<thead>
<tr>
<th></th>
<th>Average [N]</th>
<th></th>
<th>Average [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC</td>
<td>1.40</td>
<td>NN</td>
<td>0.92</td>
</tr>
<tr>
<td>30 cm</td>
<td>1.11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(b) Average of maximum force

Length: 25 cm
I: 95% confidence interval

<table>
<thead>
<tr>
<th></th>
<th>Average [N]</th>
<th></th>
<th>Average [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC</td>
<td>1.54</td>
<td>NN</td>
<td>1.06</td>
</tr>
<tr>
<td>30 cm</td>
<td>1.45</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Experimental Results (2/3)

(a) Average of average force

(b) Average of maximum force

Length: 35 cm
I: 95% confidence interval

Average of average force [N]

<table>
<thead>
<tr>
<th></th>
<th>NC</th>
<th>NN</th>
<th>30 cm</th>
<th>40 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.49</td>
<td>0.85</td>
<td>1.10</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Average of maximum force [N]

<table>
<thead>
<tr>
<th></th>
<th>NC</th>
<th>NN</th>
<th>30 cm</th>
<th>40 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.83</td>
<td>1.15</td>
<td>1.36</td>
<td>1.44</td>
</tr>
</tbody>
</table>
Experimental Results (3/3)

(a) Average of average force

(b) Average of maximum force
We investigated the effect of a neural network model for the robot position control using force information in remote robot systems with force feedback by experiment. Experimental results illustrated that the neural network model is effective.

We will deal with other factors that affect the effect of the neural network on the robot position control using force information.