Robot Assisted Rehabilitation After Stroke: Prototype Design and Clinical Evaluation

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Neurological Injury — Stroke

According to the US National Stroke Association:

- 10% of stroke survivors recover almost completely.
- 25% recover with minor impairments.
- 40% experience moderate to severe impairments that require special care.
- 10% require care in a nursing home or other long-term facility.
- 15% die shortly after the stroke.
- Approximately 14% of stroke survivors experience a second stroke in the first year following a stroke.

Most stroke patients survive with sensorimotor disorders.

http://www.who.int/mediacentre/factsheets/fs310/en/
# Manual Therapy VS. Robot-aided Training

<table>
<thead>
<tr>
<th>Manual Therapy</th>
<th>Robot-aided Training</th>
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</thead>
<tbody>
<tr>
<td>Depends more on therapist’s skill</td>
<td>Precise and consistent assistance</td>
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<tr>
<td>Tedious during long-term training</td>
<td>Interesting with video games</td>
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<tr>
<td>Large burden on therapist effort</td>
<td>Be able to work continuously without sacrificing accuracy</td>
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<tr>
<td>Rough notes after training by therapist</td>
<td>Real-time monitoring and recording during training</td>
</tr>
<tr>
<td>High cost</td>
<td>Low cost in use</td>
</tr>
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<td>...</td>
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Upper-limb Rehabilitation Robot

Virtual Training Environment
Visual/Audio Feedback

Haptic Interface
Force Feedback

Robot-aided Training Scenario

CASIA-ARM Rehab Robot
Prototype Design

Features:

- 5-bar parallel structure
  (Compact, stiff joint)
- DC motor driven, steel cable transmission
  (Smooth torque regulation, no backlash, back-drivable)

<table>
<thead>
<tr>
<th>Technical Specification</th>
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<tbody>
<tr>
<td>Degrees of freedom</td>
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<tr>
<td>Actuation</td>
</tr>
<tr>
<td>Sensors</td>
</tr>
<tr>
<td>Range of joint motion</td>
</tr>
<tr>
<td>Workspace</td>
</tr>
<tr>
<td>Motor Torque</td>
</tr>
<tr>
<td>Reduction Ratio</td>
</tr>
<tr>
<td>Force Capability</td>
</tr>
</tbody>
</table>
Force Feedback Analysis

\[ F = J(\theta_1, \theta_2)^{-T} [nT_{m1}, nT_{m2}]^T \]
High Level Controller
— Reaching Task Example

● Trajectory Planning (mimic normal human movement)

Minimum jerk trajectory between two points \((x_i, y_i)\) and \((x_d, y_d)\):

\[
\frac{x(t)-x_i}{x_d-x_i} = \frac{y(t)-y_i}{y_d-y_i} = 10\left(\frac{t}{\tau}\right)^3 - 15\left(\frac{t}{\tau}\right)^4 + 6\left(\frac{t}{\tau}\right)^5
\]

● “Assisted as Needed” Force Controller

➢ Forward direction:

\[
F_x = \begin{cases} 
-k_x (x - x_{ref}) - b_x x & x_{th} < x < x_{ref} \\
0 & x < x_{th} \text{ or } x > x_{ref}
\end{cases}
\]

➢ Vertical direction:

\[
F_y = \begin{cases} 
-k_y (y - |y_{wall}|) - b_y \dot{y} & |y| > w_{wall} \\
0 & |y| < w_{wall}
\end{cases}
\]
Low Level Controller

Impedance Controller

\[
\begin{align*}
F &= -K(X - X_{\text{ref}}) - B\dot{X} \\
T &= J^T F
\end{align*}
\]

Impedance Control Loop

Motor Torque Control Loop
Clinical Trials

- 20 min × 20 sessions (5 days/week × 4 weeks)

Experiment Group
robotic therapy

Control Group
conventional therapy
Results

- Fugl-Meyer score upper limb part (FMA-UE) is used to reflect the outcomes.
- Two evaluations are performed before trial and after trial, respectively.
- Both groups had significant gains in FMA-UE scores.
- Robotic therapy group patients have more gains than those assigned to conventional therapy, but have no significant differences.

<table>
<thead>
<tr>
<th></th>
<th>Cases</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Before trial</th>
<th>After trial</th>
<th>Z</th>
<th>p</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robotic therapy</td>
<td>12</td>
<td>M(10)F(2)</td>
<td>46.1±15.8</td>
<td>27.6±10.7</td>
<td>37.9±10.5</td>
<td>-3.063</td>
<td>0.002</td>
<td>10.3±6.3</td>
</tr>
<tr>
<td>Conventional therapy</td>
<td>12</td>
<td>M(9) F(3)</td>
<td>46.9±10.1</td>
<td>26.2±6.0</td>
<td>32.8±7.0</td>
<td>-3.064</td>
<td>0.002</td>
<td>6.7±3.1</td>
</tr>
</tbody>
</table>

* Mann-Whitney U-test is used to analyze data in the same group.
** Wilcoxon rank-sum test is used to analyze data between groups.
For more details please refer to the paper.

Thank you!