R-SAM: A Robust Stroke Rehabilitation System Augmented by Smartphone and Additive Manufacturing

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Introduction

- **Stroke**
  - Stroke survivors receive written home exercise programs after a short inpatient service.
  - The programs are insufficient:
    - Lack of instructions and motivations.
    - Low adherence.

- **Activities of Daily Living (ADL)**
  - E.g., pouring water, transporting objects, etc.
  - Training on ADL has demonstrated a great impact on stroke patients’ upper limb functional recoveries [1].

- **Our approach**
  - A portable, adaptive and robust system.
  - Smartphone (i.e., rehabilitation app):
    - Real-time instructions.
    - Fine-grained performance reports.
  - Additive manufacturing (i.e., 3D printing):
    - Remedies the rigid form of smartphone.
    - Provides ADL simulations.

Background

- **Existing In-home Rehabilitation System**
  - Virtual reality based: Obtrusiveness [2]
    - Sensor attachments.
    - Large equipment installations.
  - Robotics based: Low adaptability [3]
    - Rigid hardware and software designs
    - E.g., fixed mechanical setup.

System Overview

- **Three quantitative measures:**
  - Zero-crossing rate (ZCR): Measure sharp changes in rotating focus (see in Fig. 2) movements.
    - Measure the number of zero axis crossed by the derivative of acceleration data over the duration of movements.
  - Accuracy (ACC): Based on the references displayed on the touchscreen.
    - E.g., ACC = L_z / L_L, where L_z and L_L are lengths of the reference curve and the drawing trajectory created by the user turning a conductive gadget on the touchscreen (see in Fig. 2).

- **Rehabilitation Tool Manufacture**
  - Our tools (see in Fig. 3) are customized for users with
    - Different hand sizes
    - Different grip strengths
    - Variety of smartphones

- **Experimental Setup**
  - Three mild-moderate stroke patients (age: 66.3 ± 5.51) and five healthy elders (age: 70.6 ± 9.45).
  - Each participant performed six exercises using the same set of tools (see in Fig. 2).
  - Smoothness of the movement ⬇️ ‌➡️ NJS & ZCR⬇️

<table>
<thead>
<tr>
<th>Sets</th>
<th>Vertical Cup</th>
<th>Horizontal Bowl</th>
<th>Twist Cup</th>
<th>Pour Water</th>
<th>Turn Key</th>
<th>Dial Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>56.4±5.0</td>
<td>64.2±24</td>
<td>45.7±6.0</td>
<td>60.3±25.7</td>
<td>36.4±5.2</td>
<td>45.9±6.7</td>
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<tr>
<td>HE</td>
<td>51.5±21</td>
<td>50.9±12</td>
<td>48.4±6.0</td>
<td>46.8±8.6</td>
<td>78.4±11.3</td>
<td>97.6±11</td>
</tr>
</tbody>
</table>

Table 1. Experimental Results. SP: Stroke patient. HE: Healthy elder.

Reference