MOTORE: a Mobile Haptic Interface for Neuro-Rehabilitation

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Benefits:
- Accurate position and forces measurements
- Exercise repetition
- Increases the therapy intensity and the duration
- Enhances the patient motivation with fun and challenging exercises.

Drawbacks:
- Limited workspace
- Cumbersome
- Heavy
- Not portable
• Robotic devices used for rehabilitation therapy should:
  – Enhance the patient motivation with fun and challenging exercises
  – Increase the therapy duration while reducing its cost
  – Allow precise measurement (in terms of positioning and force exerted) useful for functional assessment
  – Be used for patients with mild or severe injuries
  – Be suitable both for home based and hospital based rehabilitation
Challenge

- Design a really portable haptic interface focused on neurological rehabilitation
- The system should provide a low cost, safe and easy-to-use, robotic-device that assists the patient and the therapist in order to achieve more systematic therapy.
  - System
    - Autonomous both for actuation and control units
  - Sensing system
    - Reduced encumbrance
    - Reduced calibration
    - Precision for providing haptic feedback
  - Control system
    - A control algorithm able to guarantee good position tracking and smooth force feedback
MOBILE roboT for upper limb neurOrtho REhabilitation

- A mobile platform for rehabilitation
- Features:
  - Embedded actuation and control
  - Autonomous
  - Large workspace
  - Omni-directional mobile robot
  - Force feedback generated by the wheels
MOTORE - components

- 3 Transwheels
- 3 DC-Micromotors + Encoders
- 3 Planetary Gearheads
- 3 H-bridges
- Optical pen with Anoto technology
- Two axes force sensor
- Three axes accelerometer
- DSP Control
- Bluetooth interface
- Battery pack
- Buzzer
- LEDs
• MOTORE kinematics
  – is based on the “Killough’s mobile robot platform”
  – Three-couples of Transwheels are placed on the circumference contour with their axes oriented at 120° and incident in the center
  – The contact with the support plane is always isostatic

• Anoto Technology
  – Infrared CCD sensor
  – Pressure sensor
  – Micro-processor
  – Bluetooth wireless link
The control unit

- **32 bit Real-time CPU**
  - 150 MHz operation frequency
  - Floating-Point Unit

- **On-Chip Memory**
  - 512 Kb Flash Memory
  - 64 Kb RAM

- **Enhanced Control Peripherals**
  - 18 PWM Outputs
  - 2 Quadrature Encoder Interfaces

- **Three 32-Bit CPU Timers**

- **12-Bit ADC (16 Channels)**
• The system is composed by three distinct units
  – Absolute position processor
  – Information aggregator unit
  – Local control unit
• The units communicate by Bluetooth interface
  – RFCOMM protocol mod BT 1.0
Usability

- Emergency stop button cable
- Handle
- Load cell
- Motor
- Omni wheels
- Rehabilitation sheet
- Forearm support
## System specifications

<table>
<thead>
<tr>
<th>Main system features</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Device mass</td>
<td>10 kg</td>
</tr>
<tr>
<td>Dimensions</td>
<td>ø300mm, h100 mm (Handle: ø80mm, h85 mm)</td>
</tr>
<tr>
<td>Optical sensor accuracy</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Maximum force</td>
<td>35 N</td>
</tr>
<tr>
<td>Workspace</td>
<td>Unlimited (1080x720 mm)</td>
</tr>
<tr>
<td>Power supply</td>
<td>NiMh battery pack 12V/10Ah</td>
</tr>
<tr>
<td>Power consumption</td>
<td>600W (peak)</td>
</tr>
<tr>
<td>Autonomy</td>
<td>75 minutes</td>
</tr>
</tbody>
</table>
Sensor data fusion has been used to obtain a better position estimation:
- Odometry and dynamic system models provide the desired relative accuracy together with sufficient bandwidth.
- Optical pen provides the desired absolute accuracy.

Redundant of information for safety condition.

EKF algorithm has been used to mix the position information.
From the non-linear model

\[
\begin{align*}
    x_k &= f(x_{k-1}, u_{k-1}, w_{k-1}), \\
    z_k &= g(x_k, v_k)
\end{align*}
\]

we get

\[
\begin{align*}
    \begin{bmatrix}
        x_{0k} \\
        y_{0k} \\
        \psi_{0k}
    \end{bmatrix}
    &=
    \begin{bmatrix}
        x_{0k-1} \\
        y_{0k-1} \\
        \psi_{0k-1}
    \end{bmatrix}
    + \frac{B}{3NL}
    \begin{bmatrix}
        \cos(\psi_{k-1}) & -\sin(\psi_{k-1}) & 0 \\
        \sin(\psi_{k-1}) & \cos(\psi_{k-1}) & 0 \\
        0 & 0 & 1
    \end{bmatrix}
    \begin{bmatrix}
        0 & \sqrt{3}L & -\sqrt{3}L \\
        0 & -2L & L \\
        1 & 1 & 1
    \end{bmatrix}
    \begin{bmatrix}
        \Delta \theta_{1k-1} \\
        \Delta \theta_{1k-2} \\
        \Delta \theta_{1k-3}
    \end{bmatrix}
    +
    \begin{bmatrix}
        w_{1k-1} \\
        w_{1k-2} \\
        w_{1k-3}
    \end{bmatrix}
    \\
    \begin{bmatrix}
        z_{1k} \\
        z_{2k}
    \end{bmatrix}
    &=
    \begin{bmatrix}
        x_{0k} \\
        y_{0k}
    \end{bmatrix}
    +
    \begin{bmatrix}
        \cos(\psi_k) & -\sin(\psi_k) \\
        \sin(\psi_k) & \cos(\psi_k)
    \end{bmatrix}
    \begin{bmatrix}
        B x_p \\
        B y_p
    \end{bmatrix}
    +
    \begin{bmatrix}
        v_{1k} \\
        v_{2k}
    \end{bmatrix}
\end{align*}
\]
Control loops

- Three loops at
  - 5 KHz: Motor control (FF + I)
  - 1 KHz: Velocity control (PI)
  - 50 Hz: “Position update”

- Open loop compensations
  - Inertia compensation
  - Torsion compensation
Feedback Generator

• The system has the capability to allow both impedance and admittance controllers

• Given the measured interaction force, the actual device posture and the commanded exercise modality, the “feedback generator” provides the desired velocity to be tracked

• For the assistive paradigm of the rehabilitation therapy it has been implemented an admittance control law along the desired direction and an impedance control law along the orthogonal one.

• The minimum driving force was set to 0.15 N by a digital limitation in the control loops to cope with user requirements
User friendly control panel to:
- command the HI behavior to manage the exercise phase
- real-time visualization of the system information (HI position, interaction force, error, system status..)
- save the user performance at the end of the exercise
Result example

- The exercise consists in training trajectories
- The patient has to follow a path shown on the screen in front of him.

- **Good repeatability of the user’s trajectory**
- **No drift in the robot position estimation**
Preliminary Experimentation
Feasibility pilot study

• 4 hemiparetic patients involved (3 affected on the right side, 1 on left side) aged from 16 to 67 years old
• Target size accorded to anthropometric measure (Full, Medium, Small size)
• 2 chronic patients (acute event at least 6 months before)
• 2 sub-acute patients (acute event less than 2 months before)
Feasibility pilot study (II)

- Stage of recovery evaluated by Chedoke McMaster Stroke Assessment Scale:
  - 1 Flaccid paralysis; 2 mild spasticity; 3 marked spasticity; 4 spasticity decreases; 5 spasticity wanes; 6 coordination and patterns of movement are near normal; 7 normal

- Chedoke of sub-acute patients: 2-5
- Chedoke of chronic patients: 2-4
- Shoulder, elbow and wrist spasticity evaluated before and after treatment by Modify Ashworth Scale (0-5 points)
- All patients were able to perform little voluntary movement
- Number of sessions performed: from 2 to 6 sessions
- Sessions duration: from 10 to 20 minutes
• The system need some further little improvement but it seems to be useful
• All patients (mild and moderate impaired) have been able to use the device
• No increase in muscles tone after treatment
• Treatment is well accepted from patients

_Pilot study with pre-post treatment study design, bigger sample size and an increased number of sessions is needed before programming a Randomized Clinical Trial in order to evaluate the effectiveness of the device_
Conclusions

• We present a new rehabilitation device that is portable and it could be used for home rehabilitation

• The system is completely autonomous both for actuation and control aspects

• The system can be indifferently used with the right arm or the left one without any reconfiguration procedure

• Force feedback and audio-visual feedback are used to increase the patient motivation
• Experimentation
• Embed the Anoto Technology to do not need the PC
• “Real-time” reference trajectory editing
• EKF with time-delay measurement compensation
  – The absolute position signal is delayed respect to the encoders signal
  – The idea is to correlate the measure not with the current position estimation but with the estimation who the pen data refer to
Acknowledgments

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Thank you for your attention

Questions?