MOTORE: a Mobile Haptic Interface for Neuro-Rehabilitation

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Rehabilitation Robotics

- 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

ExoArm

MIT MANUS

Emul

MEMOS

Rationale

- 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

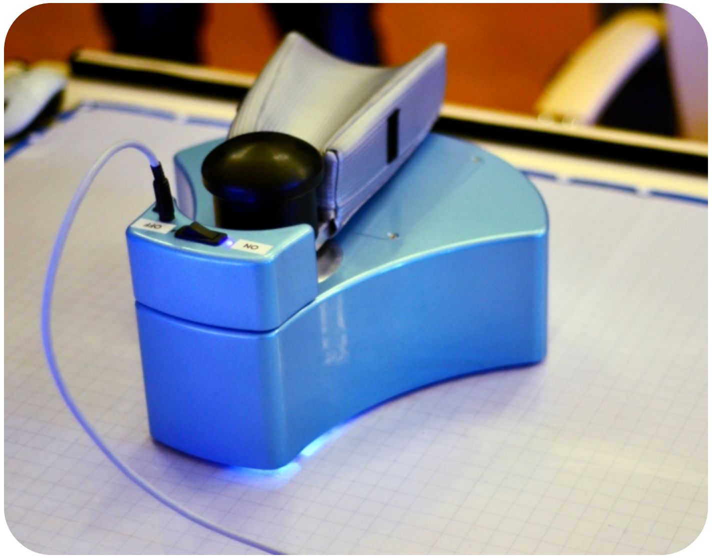
Challenge

- 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

MOTORE

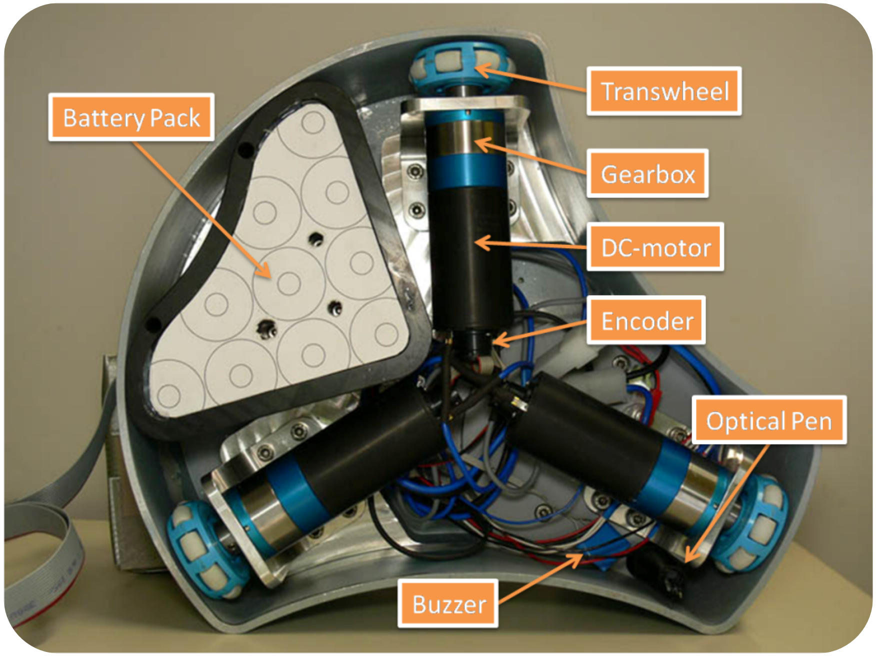
MObile roboT for upper limb neurOrtho REhabilitation

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



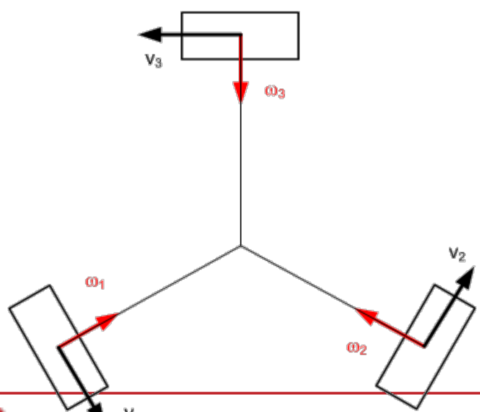
MOTORE - components

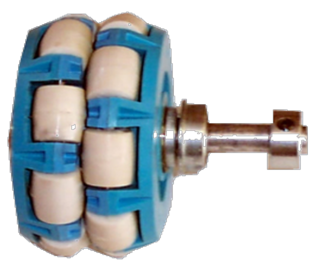
- 3 Transwheels
- 3 DC-Micromotors + Encoders
- 3 Planetary Gearheads
- 3 H-bridges
- Optical pen with Anoto technology
- Two axes force sensor
- Three axes accelerometer
- DSP Control
- Bluetooth interface
- Battery pack
- Buzzer
- LEDs



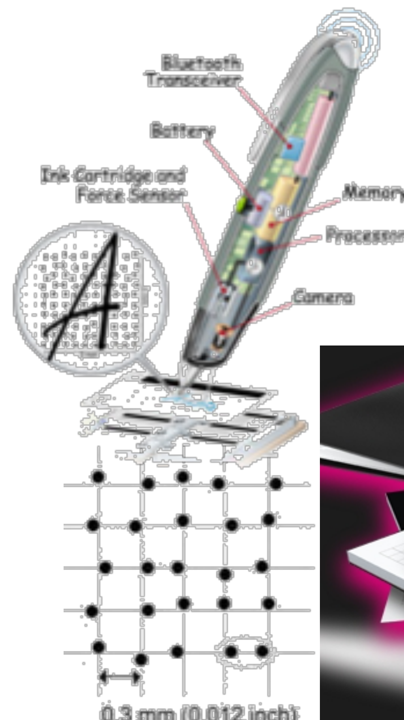
Remarks

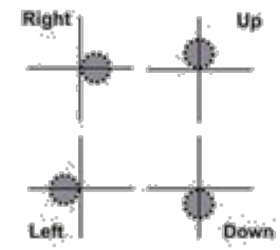
- MOTORE kinematics
  - is based on the "Killough's mobile robot platform"
  - Three-couples of Transwheels are placed on the circumference contour with their axes oriented at 120º and incident in the center
  - The contact with the support plane is always isostatic





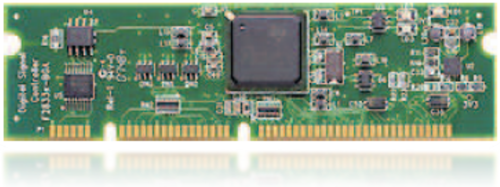
- Anoto Technology
  - Infrared CCD sensor
  - Pressure sensor
  - Micro-processor
  - Bluetooth wireless link



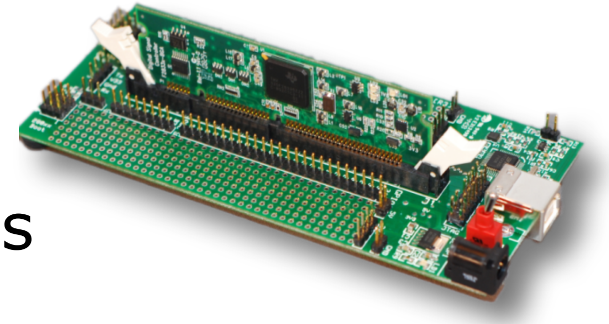


The control unit

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

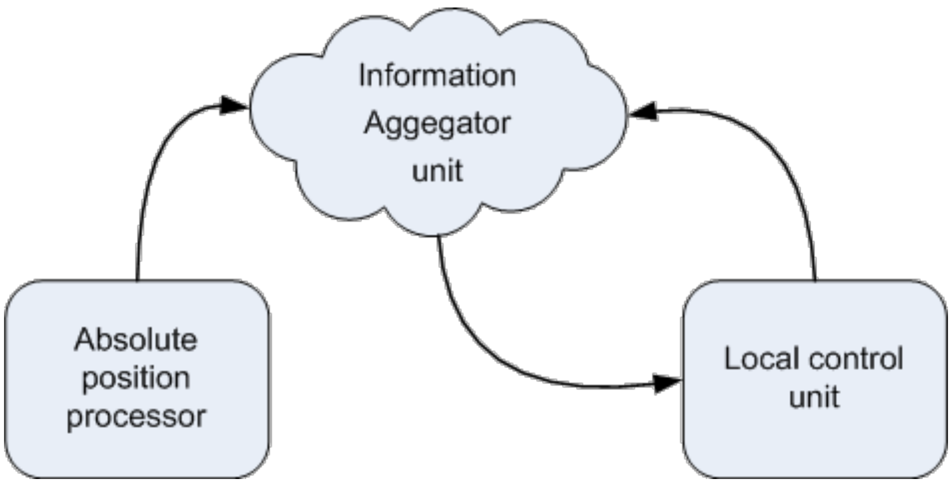


- On-Chip Memory
  - 512 Kb Flash Memory
  - 64 Kb RAM
- Enhanced Control Peripherals
  - 18 PWM Outputs
  - 2 Quadrature Encoder Interfaces



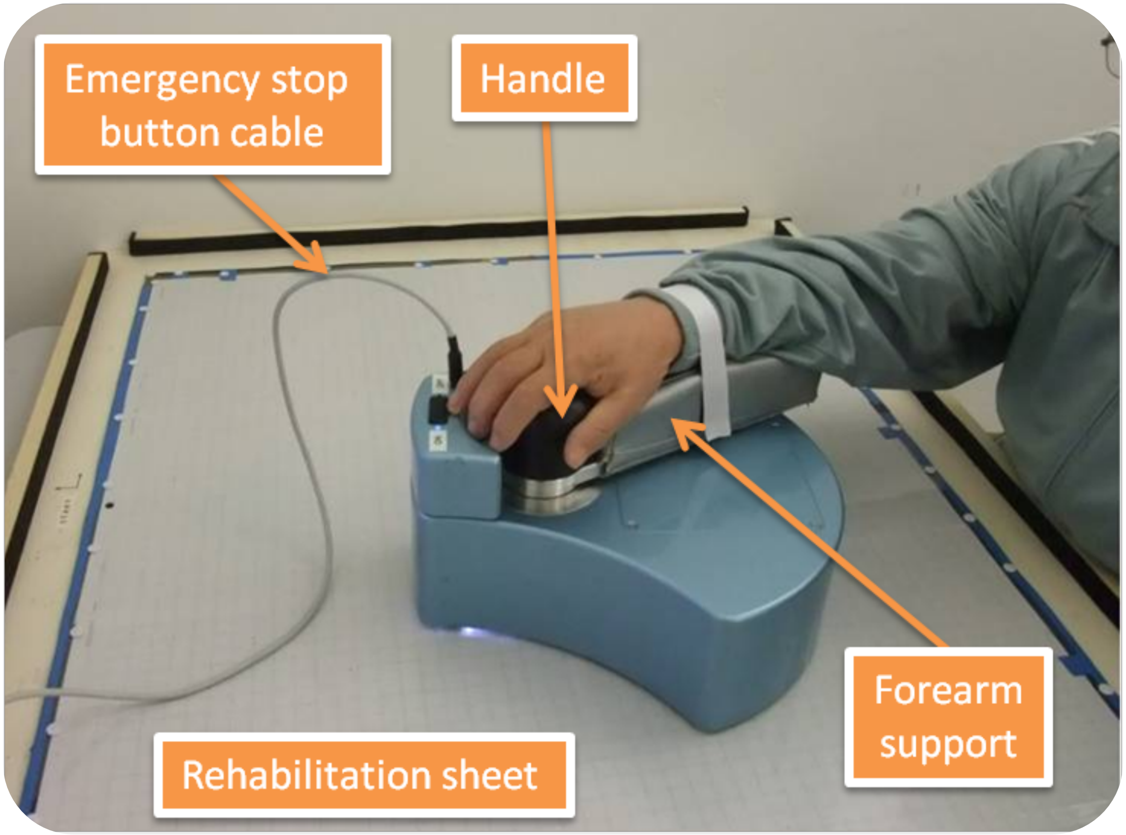
- Three 32-Bit CPU Timers
- 12-Bit ADC (16 Channels)

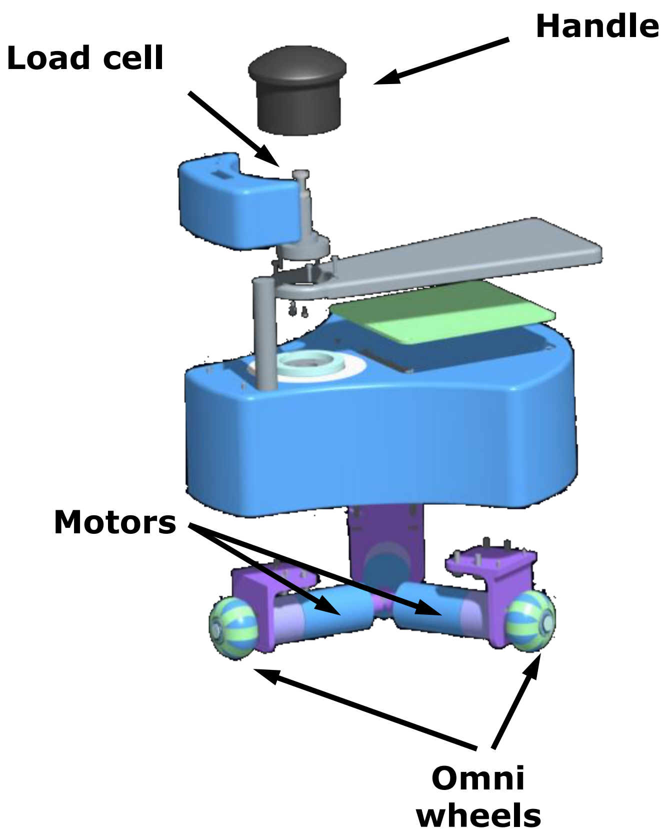
System Architecture



- 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
Forearm support
Rehabilitation sheet

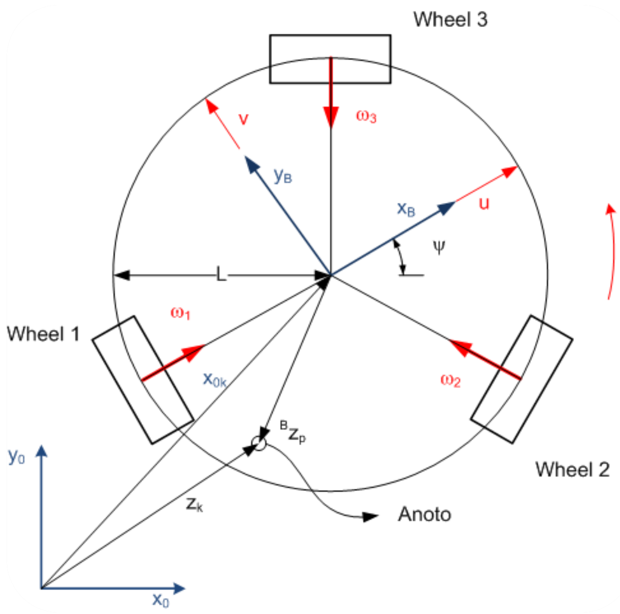

Handle
Load cell
Motors
Omni wheels

System specifications

Main system features	
Device mass	10 kg
Dimensions	ø300mm, h100 mm (Handle: ø80mm, h85 mm)
Optical sensor accuracy	0,4 mm
Maximum force	35 N
Workspace	Unlimited (1080x720 mm)
Power supply	NiMh battery pack 12V/10Ah
Power consumption	600W (peak)
Autonomy	75 minutes

Localization problem

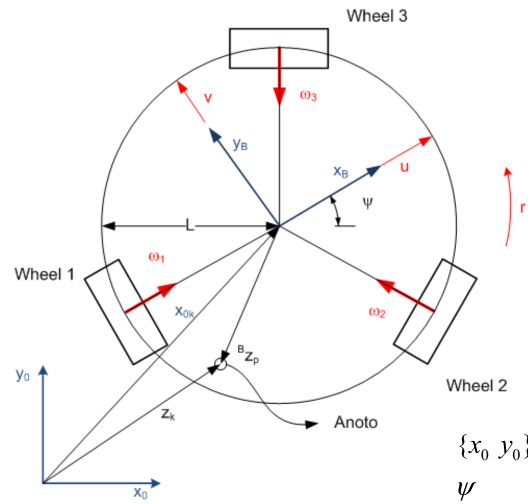
- Sensor data fusion has been used to obtain a better position estimation
  - Odometry and dynamic system models provide the desired relative accuracy together with sufficient bandwidth
  - Optical pen provides the desired absolute accuracy
- Redundant of information for safety condition
- EKF algorithm has been used to mix the position information



MOTORE - EKF

From the non-linear model

$$\begin{cases} x_k = f\left(x_{k-1}, u_{k-1}, w_{k-1}\right) \\ z_k = g\left(x_k, v_k\right) \end{cases}$$



$\{x_0 \; y_0\}$ *Abs ref*; $\{x_B y_B\}$ *Body ref*

ψ *Angle between Abs ref and Body ref*

${}^B z_p = [{}^B x_p, {}^B y_p]^T$ *pen position in Body ref*

$z_k = [z_{1k}, z_{2k}]^T$ *measure in Abs ref*

$x_k = [x_{0k}, y_{0k}, \psi_{0k}]^T$ *state in Abs ref*

$L =$ *MOTORE radius*; $N =$ *gear reduction*

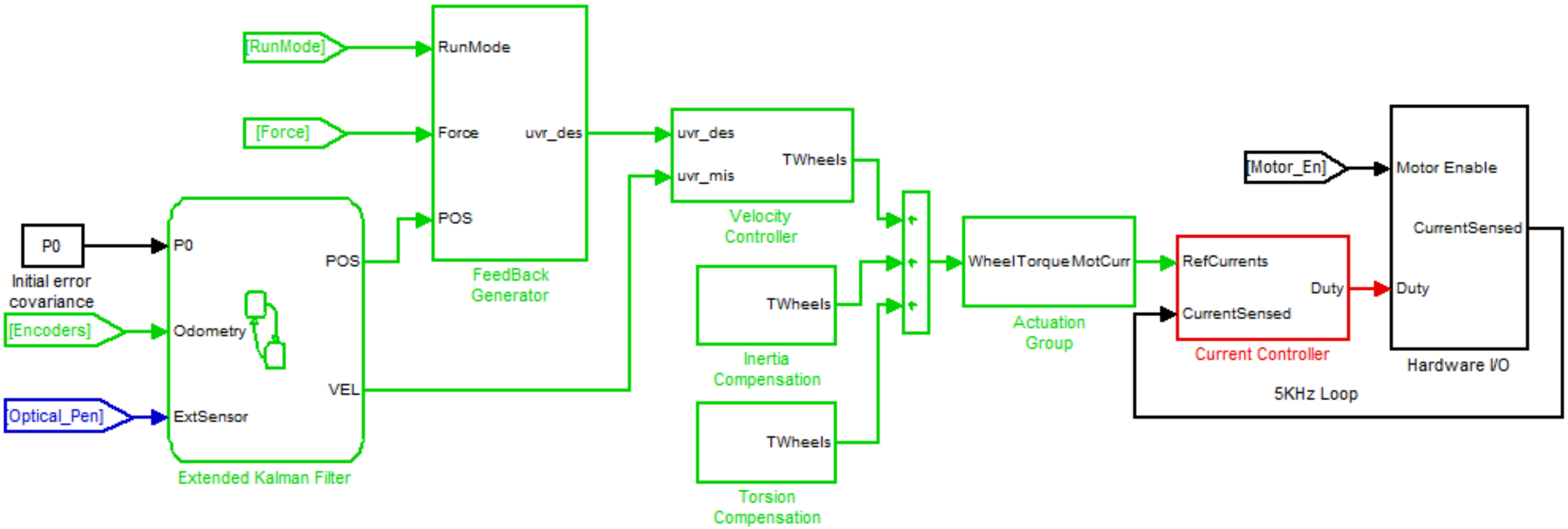
$B =$ *wheel radius*

we get

$$\begin{cases} \begin{bmatrix} x_{0k} \\ y_{0k} \\ \psi_{0k} \end{bmatrix} = \begin{bmatrix} x_{0k-1} \\ y_{0k-1} \\ \psi_{0k-1} \end{bmatrix} + \dfrac{B}{3NL} \begin{bmatrix} \cos\left(\psi_{k-1}\right) & -\sin\left(\psi_{k-1}\right) & 0 \\ \sin\left(\psi_{k-1}\right) & \cos\left(\psi_{k-1}\right) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & \sqrt{3}L & -\sqrt{3}L \\ -2L & L & L \\ 1 & 1 & 1 \end{bmatrix} \left(\begin{bmatrix} \Delta\theta_{1k-1} \\ \Delta\theta_{1k-2} \\ \Delta\theta_{1k-3} \end{bmatrix} + \begin{bmatrix} w_{1k-1} \\ w_{1k-2} \\ w_{1k-3} \end{bmatrix} \right) \\ \begin{bmatrix} z_{1k} \\ z_{2k} \end{bmatrix} = \begin{bmatrix} x_{0k} \\ y_{0k} \end{bmatrix} + \begin{bmatrix} \cos\left(\psi_k\right) & -\sin\left(\psi_k\right) \\ \sin\left(\psi_k\right) & \cos\left(\psi_k\right) \end{bmatrix} \begin{bmatrix} {}^B x_p \\ {}^B y_p \end{bmatrix} + \begin{bmatrix} v_{1k} \\ v_{2k} \end{bmatrix} \end{cases}$$

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

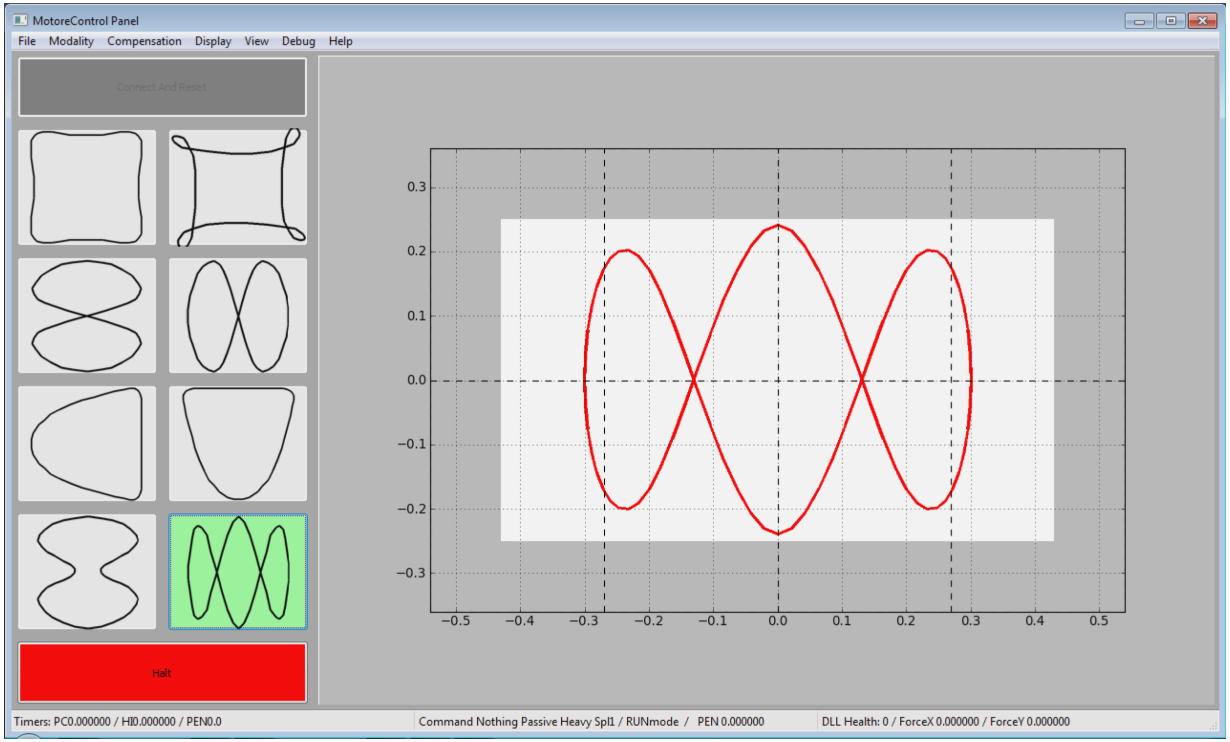


Feedback Generator

- 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

Graphical User Interface

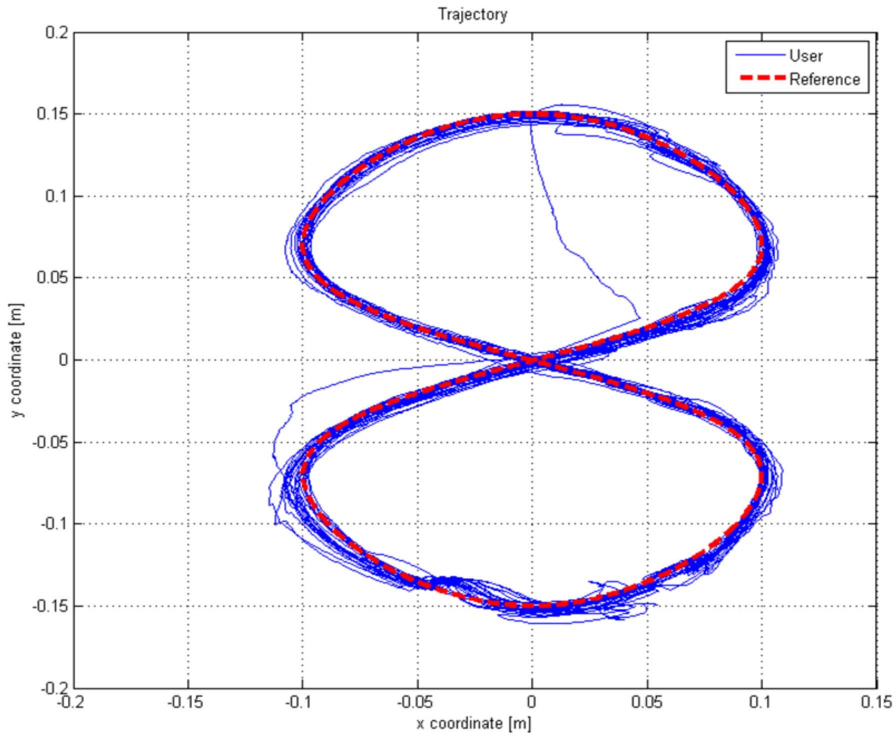
- User friendly control panel to:
  - command the HI behavior to manage the exercise phase
  - real-time visualization of the system information (HI position, interaction force, error, system status..)
  - save the user performance at the end of the exercise



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*



Video

Admittance controller test

Rehabilitation Example

GUI Demonstration

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

Feasibility pilot study - Results

- 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

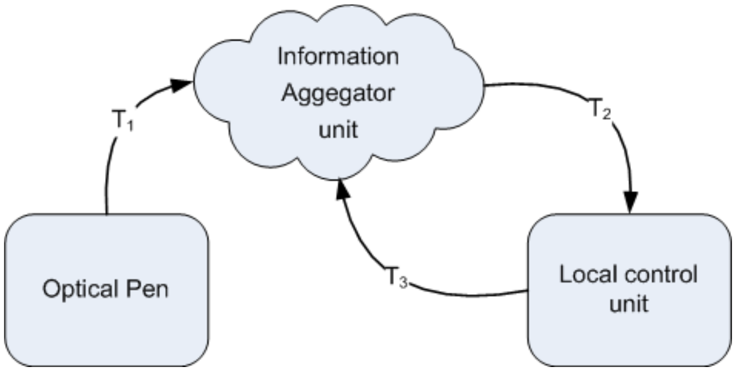
Pilot study with pre-post treatment study design, bigger sample size and an increased number of sessions is needed before programming a Randomized Clinical Trial in order to evaluate the effectiveness of the device

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

Work in progress

- 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



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Humanware

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Thank you for your attention

Questions?