ECHORD call1 experiment

MAAT

Multimodal interfaces to improve therApeutic outcomes in robot-Assisted rehabiliTation

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Experiment MAAT

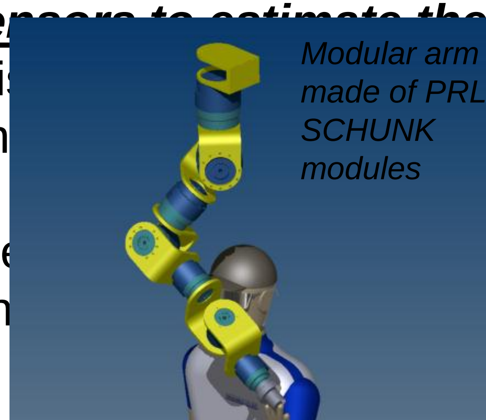
Objective

To develop a new rehabilitation robotic system able to:

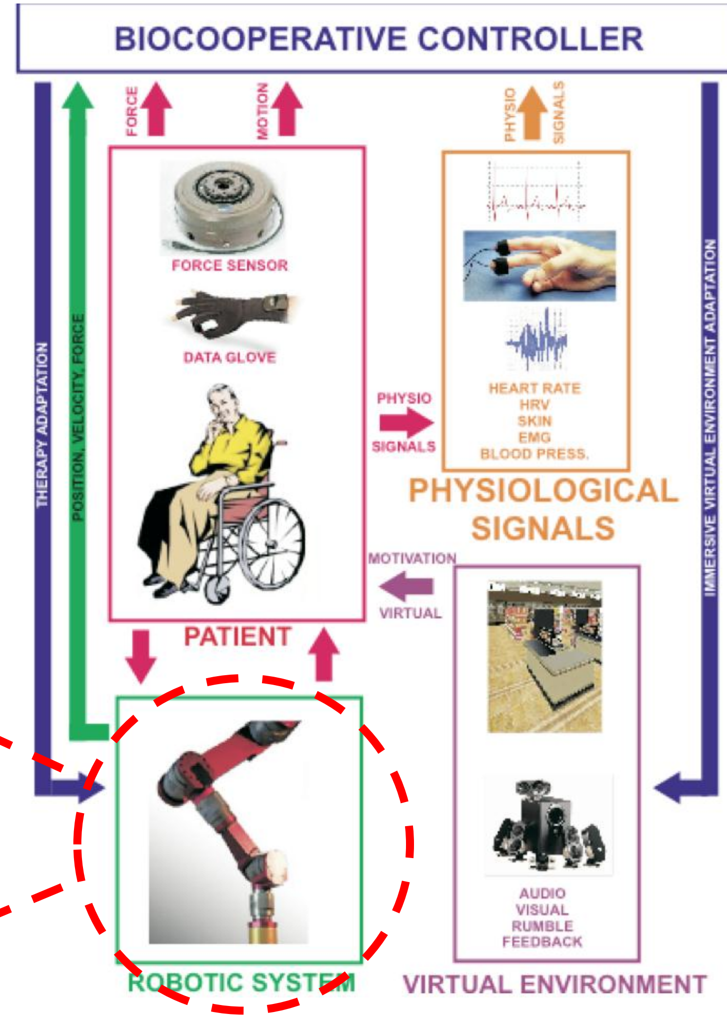
- ***Maximize patient motivation*** and involvement in the therapy.
- ***Continuously asse*** ***he patient recovery*** fr neurological viewpo ion to the issue of safety i tion.

Main novelties

- ***To include the patient into the control loop.***
- ***The use of bio-se*** ***state of the patient.*** Thi to adaptively and dyn exity of the therapy and immersive virtual re ance with specific patien



Rehabilitation human-robot co-worker scenario



MAAT workplan – activities carried out in M1-M6

- Task 2: Development of a multimodal interface [M1-M11]
  - Task 2.1: ***State of the art*** in the evaluation of patient's intention and physiological state (**UMH**)
  - Task 2.2: Definition, ***selection of equipment for monitoring*** patient behavioral and physiological state (**UMH**)
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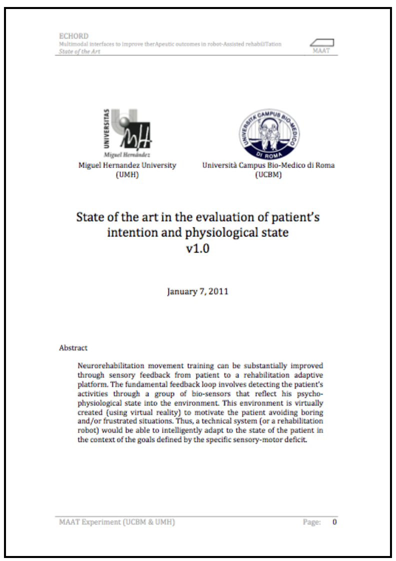
- Task 5: Dissemination and Exploitation

Task 2.1: State of the art

- State of the art v1.0 is available at this moment.
- The document is published in the MAAT web (located temporarily at hal.umh.es/maat).



ECHORD
Multimodal interfaces to improve therApeutic outcomes in robot-Assisted rehabiliTation
State of the Art
MAAT

Miguel Hernandez University (UMH)

Università Campus Bio-Medico di Roma (UCBM)

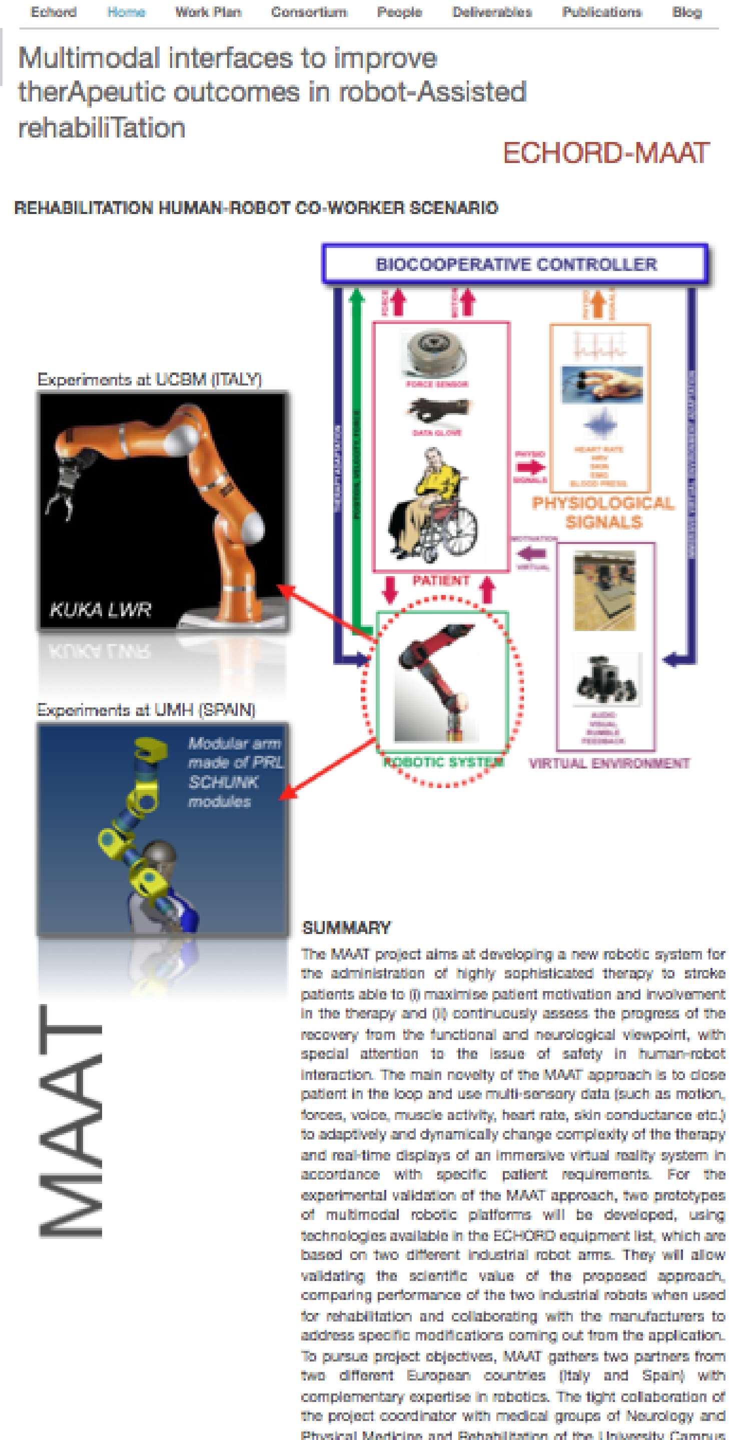
State of the art in the evaluation of patient's intention and physiological state
v1.0

January 7, 2011

Abstract

Neurorehabilitation movement training can be substantially improved through sensory feedback from patient to a rehabilitation adaptive platform. The fundamental feedback loop involves detecting the patient's activities through a group of bio-sensors that reflect his psycho-physiological state into the environment. This environment is virtually created (using virtual reality) to motivate the patient avoiding boring and/or frustrated situations. Thus, a technical system (or a rehabilitation robot) would be able to intelligently adapt to the state of the patient in the context of the goals defined by the specific sensory-motor deficit.

MAAT Experiment (UCBM & UMH) Page: 0



Task 2.1: State of the art

- Bio-signals considered to estimate the physiological state of humans:
  - Voice sound.
  - Blood pressure.
  - ECG, EEG, EMG, EOG
  - (electrocardiography, electroencephalography, electromyography, electrooculography).
  - Functional magnetic resonance imaging (fMRI).
  - Respiratory effort and frequency.
  - Skin response (conductivity and temperature).
  - Etc.
- Some of them are well studied and the “State of the art” document presents the first conclusions.
- Several bio-sensors have been acquired (from G-TEC):

  (we are using a G-TEC amplifier previously acquired by the group)

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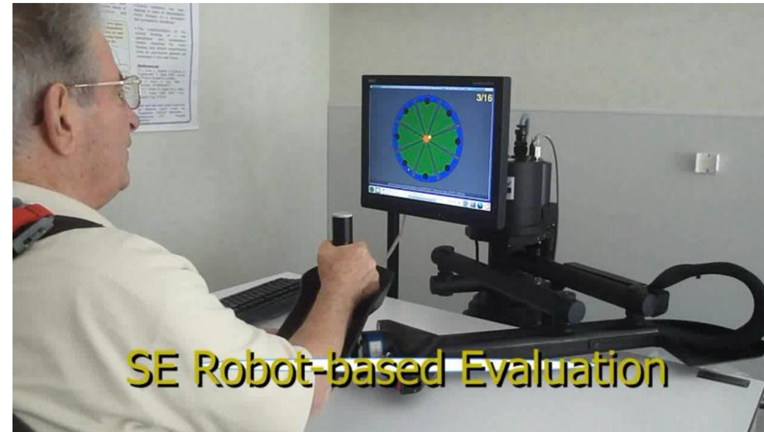
Robot-based evaluation

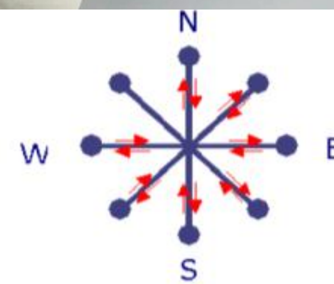


Kinematic indices:

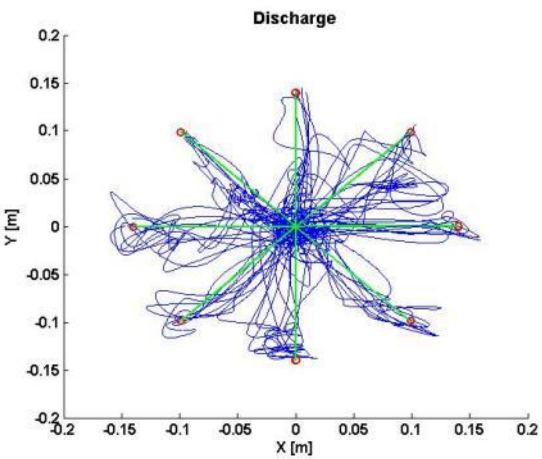
- Accuracy
- Smoothness
- Path length
- Motion duration
- Motion direction
- Motion velocity

Dynamic indices:

- Force applied during motion (total force and useful force)
- Work expended during motion (total work and useful work)



Unperturbed point-to-point motion

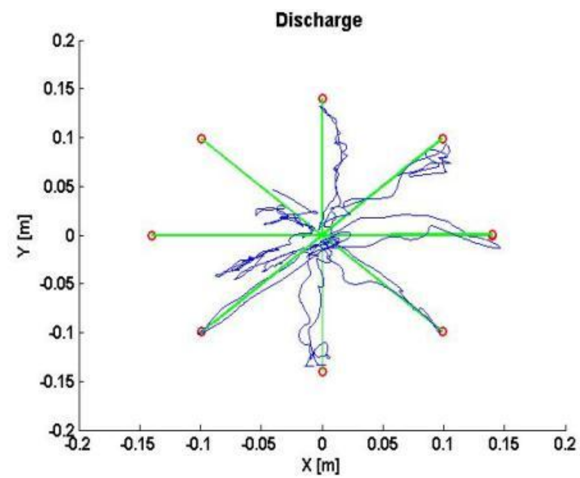


Minimum-jerk trajectory

$$x(t) = x_0 + (x_0 - x_f)(15\tau^4 - 6\tau^5 - 10\tau^3)$$
$$y(t) = y_0 + (y_0 - y_f)(15\tau^4 - 6\tau^5 - 10\tau^3)$$

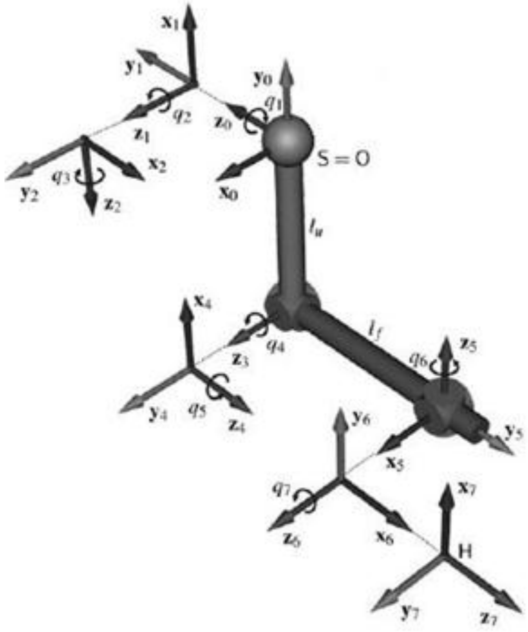
Resistive force

$$\tau = -J^T(q)(K_P\tilde{x} + K_D\dot{x})$$
$$\tilde{x} = x - x_d$$



Zollo L, Gallotta E, Guglielmelli E, Sterzi S “Robotic Technologies and Rehabilitation: New Tools for Upper-limb Therapy and Assessment in Chronic Stroke”, EUROPEAN J PHYS REHABIL MEDICINE, 2011, in press.

Reconstruction of upper-limb joint angles for motor therapy with an end-effector machine

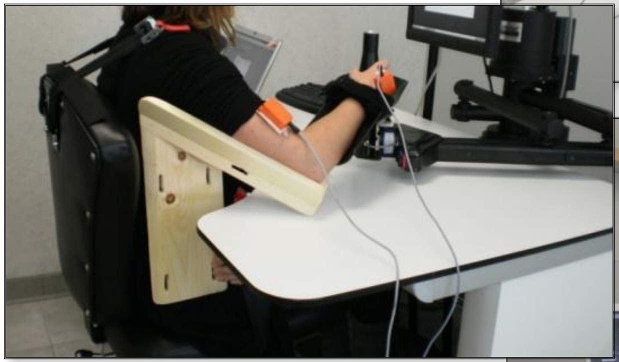


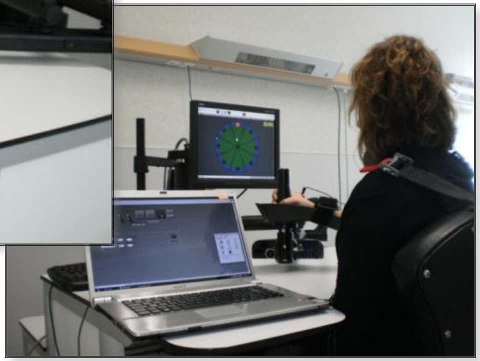
The degrees of freedom (DOFs) of the upper limb are not directly controllable when an end-effector rehabilitation machine is used for motor therapy.

The joint use of position sensors embedded in the robot with wearable sensors allow reconstructing angles of upper-limb 7 DOFs.

$$H(\vec{q}) = T_7^0(\vec{q})$$

$$Ts = T_3^0 = T_1^0 T_2^1 T_3^2$$
$$Te = T_4^3 Trans(z_4, lf) \longrightarrow H = TsTeTw$$
$$Tw = T_7^4 = T_5^4 T_6^5 T_7^6$$



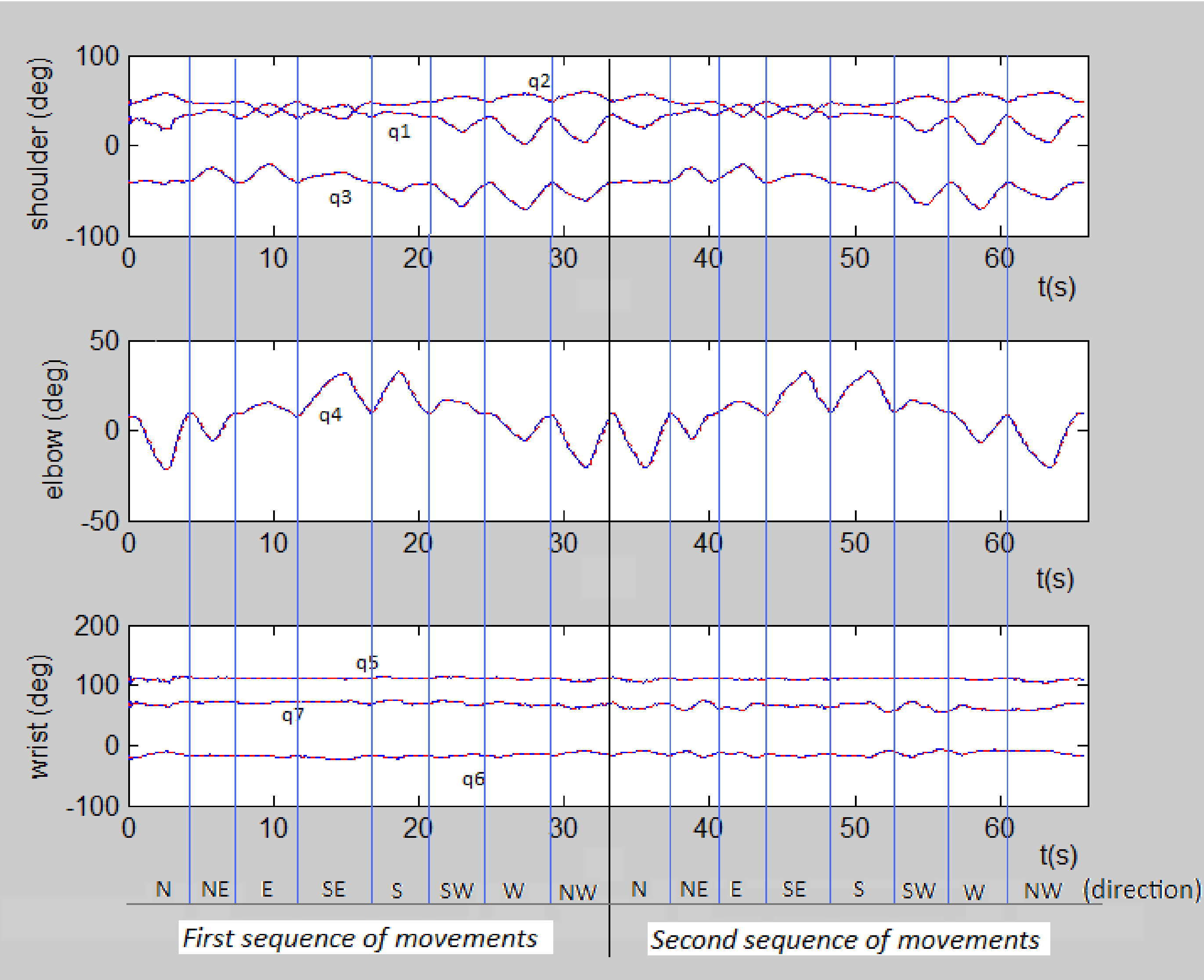


<u>Accelerometers put on the upper arm segment allows determining aditional coordinates.</u>

An orientation sensor is used to determine the hand orientation.

[Mihelj M. *Human arm kinematics for robot based rehabilitation*. Robotica. 2006, 24: pp. 377-383.]

Reconstructed and computed ***arm angles*** during typical point-to-point movements



estimated angles
computed angles

Estimated angles are the outcome of the ***kinematic recontruction algorithm.***

Computed angles are calculated ***trough an Inverse Kinematic*** Algorithm based on an Augmented Jacobian.

Absolute value of the difference between estimated and computed arm angles

mean (deg)
0.6064

standard deviation (deg)
0.1345

[Mihelj M. *Human arm kinematics for robot based rehabilitation*. Robotica. 2006, 24: pp. 377-383.]
[Kreutz-Delgado K, Long M, Seraji H. *Kinematic analysis of 7 DOF anthropomorphic arms*. IEEE International Conference on Robotics and Automation. Cincinnati, OH, USA, pp. 824-830, 1990.]

MAAT workplan – work in progress

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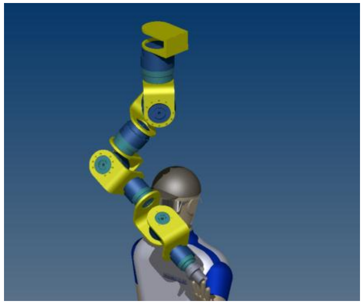
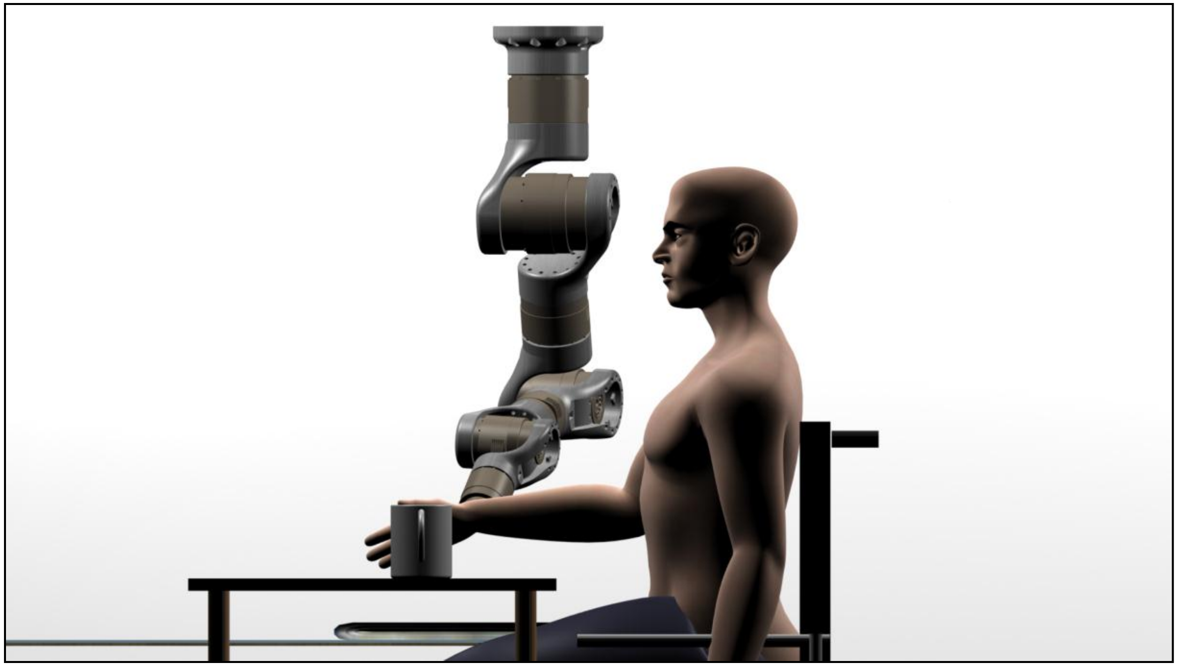
Rehabilitation robotic platforms
(to be tested in MAAT are based on this idea)

The patient is performing some activity of daily living and the robot is assisting this activity.

KUKA lightweight robot

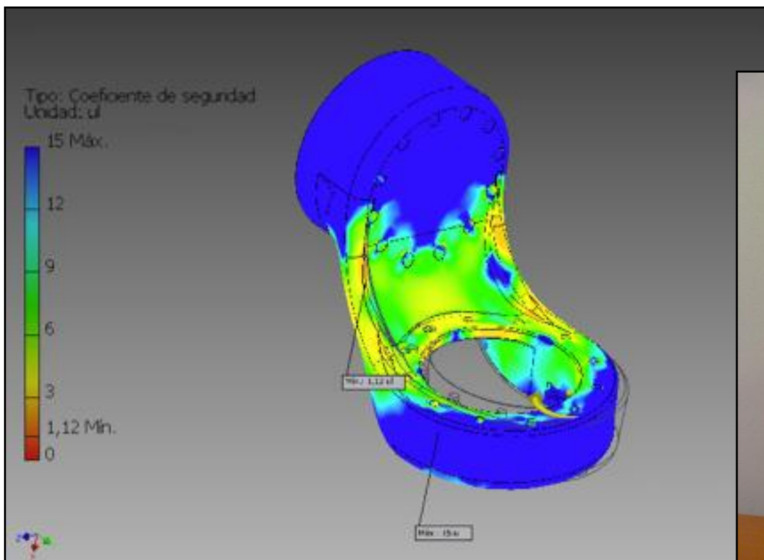


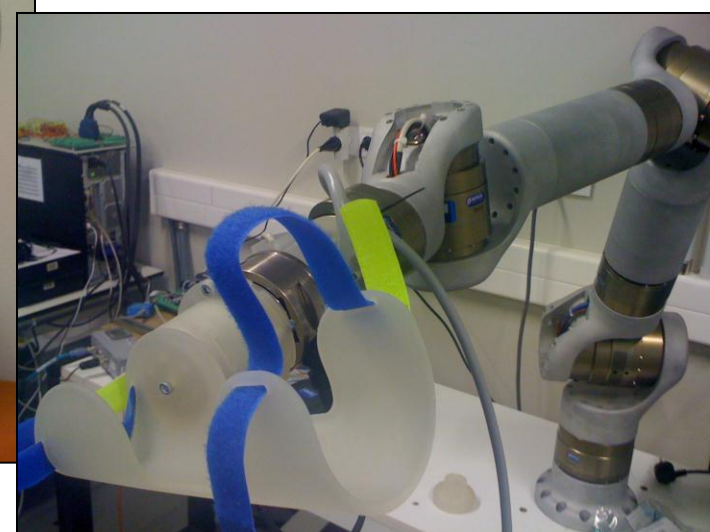
Modular arm based on SCHUNK modules



In this sense, we have designed and mounted a device based on SCHUNK modular motors:

Steps performed:
-Finite Element analysis for Mechanical design.
-Link milling and robot mounting.
-Orthopedic adapter design and manufacturing.





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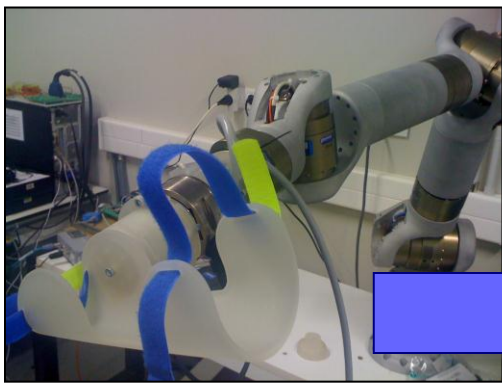
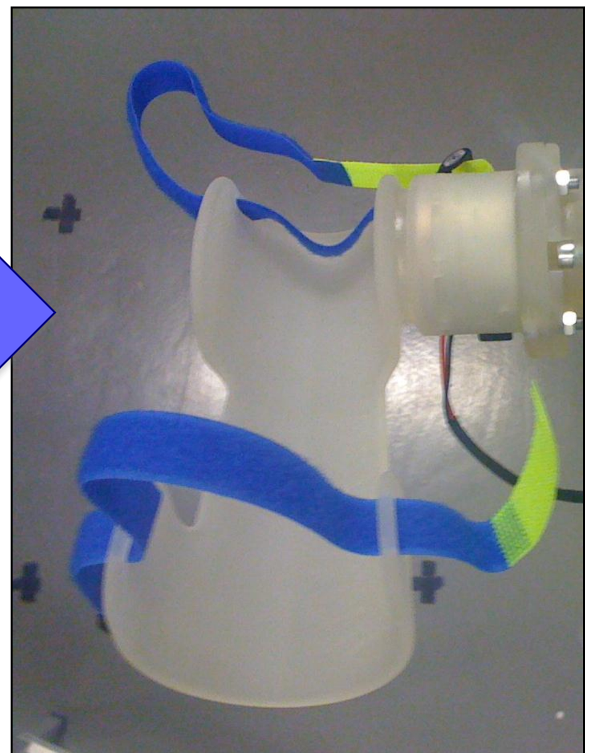
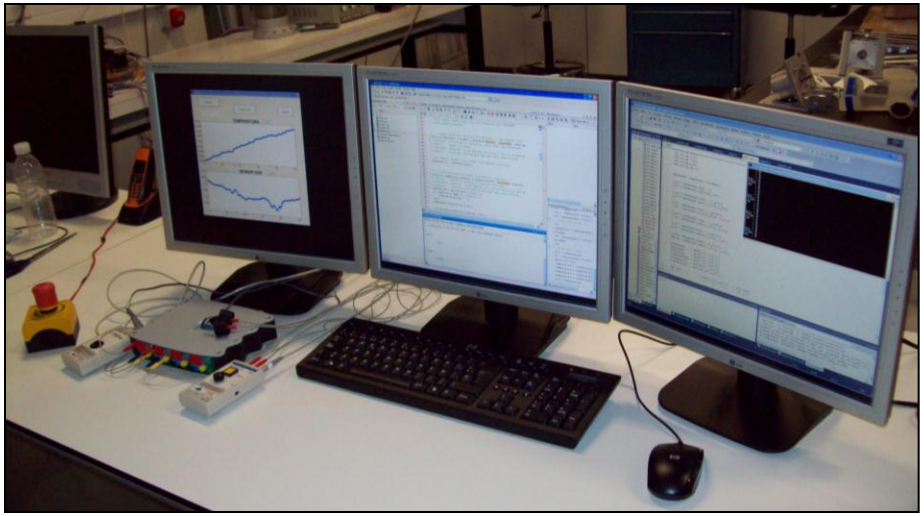
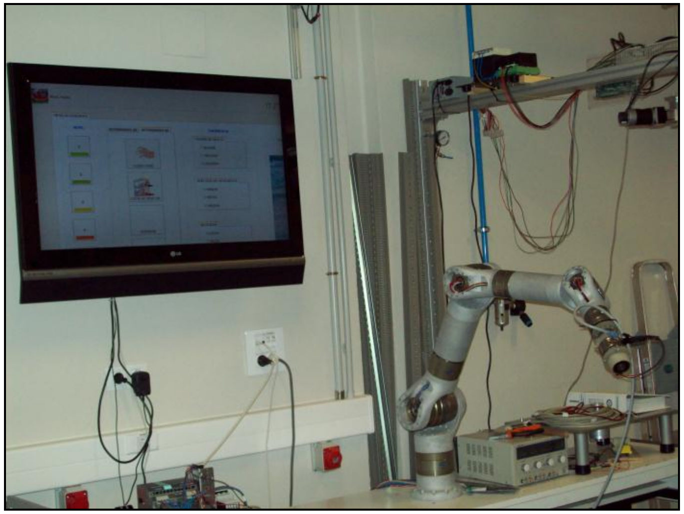




Rehabilitation robot set-up has the following elements:

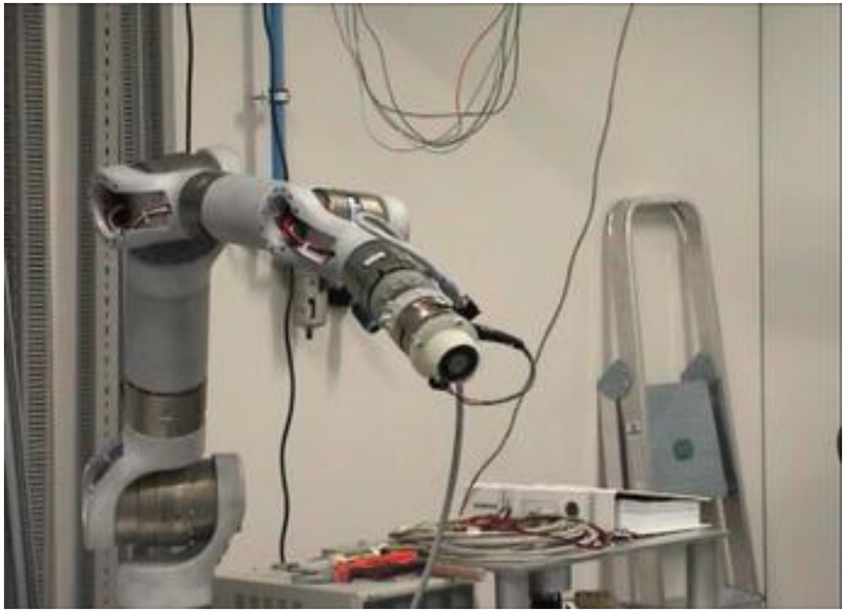
-Development workspace (group of PCs, emergency button and bio-signals amplifier).
-Patient workspace (robot for rehabilitation and TV screen for virtual reality).





Interaction between the rehabilitation robot and the patient are shown in the following videos:

-Video 1: Robot-orthosis adaptation.
-Video 2: Patient interacting with a virtual reality environment.



Video 1

Video 2

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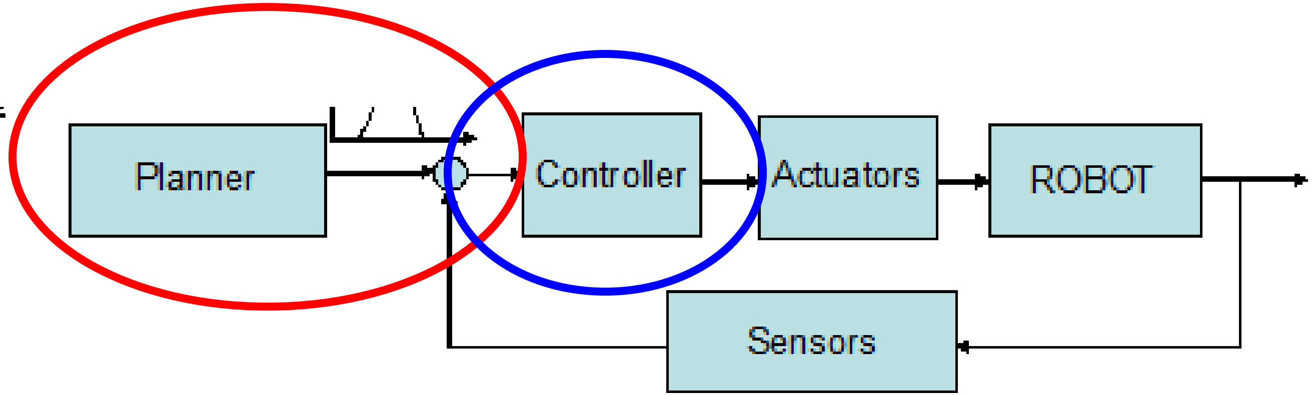
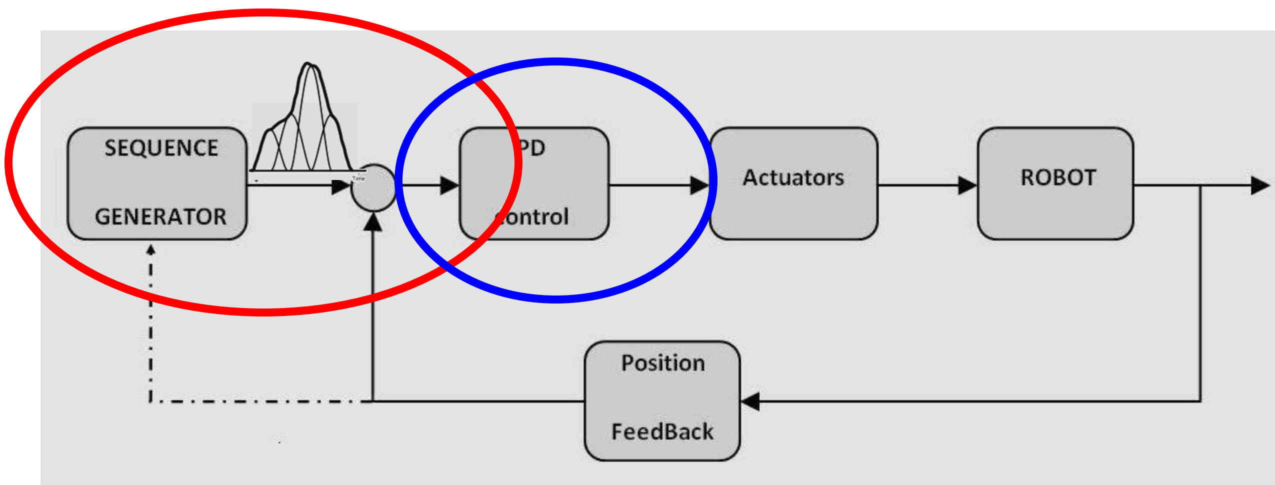
[A. Salerno, L. Zollo, E. Guglielmelli, "Submovement Composition for Motion and Interaction Control of a Robot Manipulator", IEEE/RSJ International Conference on Intelligent Robots and Systems , September 25-30, 2011, San Francisco, submitted.]

Proposed Approach: Submovement-based Rhythmic Controller

- ***dynamic sequence generator*** closed in the feedback loop.
- It is able to online generate new sequences of submovements, opportunely scaled in amplitude and occurrence.
- ***The low level control can always be implemented by means of standard PD.***
- It is possible to control position error (or interaction force) acting on the sequence of submovements, and keeping control gains constant.

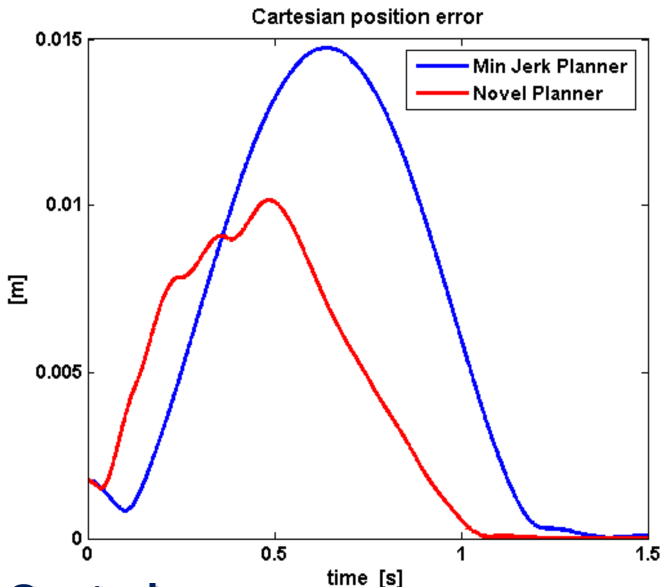


Traditional Approach



Submovement-based approach

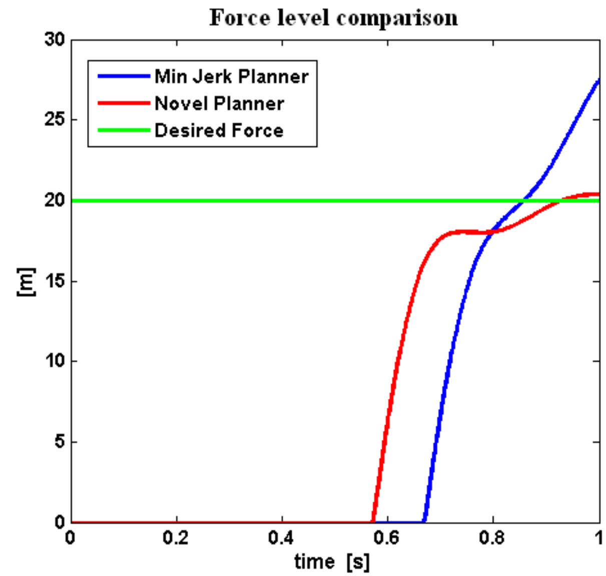
Simulation Results: Motion & Interaction Control



Motion Control

Gain K_P [N/m]	Mean err [m]	Peak err [m]
500	0.009018	0.014740
550	0.008489	0.013843
600	0.008018	0.013047
650	0.007596	0.012335
700	0.007216	0.011696
750	0.006872	0.011119

K_P=diag{500, 500} N/m K_D={20, 20} Ns/m



Interaction Control

Gain K_P [N/m]	Force [N]
500	27.480859
450	26.194747
400	24.820003
350	20.222521
300	18.613506
250	17.254733

- ***Accuracy improvement using this approach is equivalent to the one obtained in a traditional PD control, increasing proportional gain from 500 N/m to 750 N/m.***
- Submovement modulation allows achieving the same level of force obtained in a traditional PD control with K_P = 350 N/m.

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Dissemination activities

- Organization of workshops and special session:
  - ***<u>Workshop on “Future Trends in Rehabilitation Robotics”.</u>*** BioRob 2010, September 26, 2010, Tokyo, Japan
  - ***<u>Special Issue on “Rehabilitation Robotics” for the Medical and Biological Engineering and Computing journal</u>***, 2011
- Publications in International Journals:
  - Zollo L, Gallotta E, Guglielmelli E, Sterzi S. Robotic technologies and rehabilitation: new tools for upper-limb therapy and assessment in chronic stroke. ***<u>European Journal of Physical and Rehabilitation Medicine</u>***. 2011, ***in press.***
  - Zollo, L., Rossini, L., Bravi, M., Magrone, G., Sterzi, S., Guglielmelli, E., Quantitative evaluation of upper-limb motor control in robot-aided rehabilitation, Medical and Biological Engineering and Computing, 2011, ***<u>submitted</u>***.
- Publications in Books (***<u>book chapter</u>***):
  - Zollo L, Accoto D, Sterzi S, Guglielmelli E. Rehabilitation Robotics, Therapeutic Robotics. Springer Handbook of Medical Technology, K. Rüdiger, K.-P. Hoffmann, R.S. Pozos, (Eds.), Chap. 44, 2011 (ISBN: 978-3-540-74657-7).
- Conference Proceedings:
  - L. Zollo, A. Salerno, L. Rossini, E. Guglielmelli, “Submovement composition for motion and interaction control of a robot manipulator”, ***<u>BIOROB</u>*** 2010 - IEEE/ RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics, Tokyo, Japan, 2010.
  - A. Salerno, L. Zollo, E. Guglielmelli, “Submovement Composition for Motion and Interaction Control of a Robot Manipulator”, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), September 25-30, 2011, San Francisco, ***<u>submitted</u>***.

The End