Dynamics Identification of human-like systems

Global Identification Methodology

. MODELLING THE DYNAMICS Modelling based on the fundamental equations of dynamics obtained for multi-body systems.

$$\tau = \Gamma + Q = H(q,\dot{q},\ddot{q},I_p) + \tau^{vef}$$

- T vector of joint torques
- \mathbf{I} vector of joint forces and torque due to actuation
- Q vector of generalized efforts (projection of external efforts)
- H vector of inertial, Coriolis, centrifugal, gravity forces
- Q vector of joint angles
- vector of inertial parameters: mass, inertia, first moment of inertia
- au^{vej} vector of visco-elasticity and friction forces of joints

2. IDENTIFICATION MODEL Dynamic **model linear** in inertial parameters and viscoelastic properties.

$$\tau = Y(q,\dot{q},\ddot{q}) \phi$$

- Y regressor matrix or observation matrix
- Φ vector parameters to estimate

After sampling along a trajectory, identification model solved by linear least-squares method:

- allow to compute indicators to interpret the results: Condition number of the regressor matrix and standard deviation for each parameter estimated

3. EXCITING TRAJECTORIES

A good estimation relies on: 1) an appropriate model to describe the system, (2) accurate measurements,

(3) properly chosen movements that can excite the dynamics to identify, named persistently exciting trajectories

4. BASE PARAMETERS

Only minimal set of parameter describing the model can be identify: Base parameters

Can be computed symbolically: essential base parameters, dependant only on kinematic structure of the system. Can be computed numerically: in addition to essential base parameters parameters not exited by the motion are grouped or suppressed.

5. VALIDATIONS

Dynamic model and Identification model

 $oldsymbol{Y}_{B1}oldsymbol{\phi}_B=igcep\}$] $oldsymbol{K}_{k1}oldsymbol{F}_k$

of humanoid robots

A-priori data often not known. Validations consist in comparing joint torques or efforts measured to the computed one using the identification model and the estimated parameters. **Direct validation**: motion in the data set used for identification. **Cross-validation**: motion not used for identification

BIBLIOGRAPHY

Cross-validation with a left-fronted squat

- G. Venture, K. Yamane, and Y. Nakamura, "In-vivo estimation of the human elbow joint dynamics during passive movements based on the musculo-skeletal kinematics computation," in IEEE/Int. ICRA, Orlando, ÚSA, May 2006, pp. 2960–2965. - M. Khalil, W. Gautier and J.F. Kleinfinger, "Automatic generation of identification models of robots," Int. Jour. of Robotics and

Automation, vol. 1, no. 1, pp. 2–6, 1986. - J.M. Winters and L. Stark, "Analysis of fundamental human movement patterns through the use of in-depth antagonistic

muscle model," IEEE Trans. on Biómedical Engineering, vol. 32, no. 10, pp. 826–839, 1985.

- Khalil W. and Dombre E., "Modeling, identification and control of robots", Hermès Penton, London-U.K, 2002. - M. Gautier and W. Khalil, "Exciting trajectories for the identification of base inertial parameters of robots," Int. Jour. of Robotic Research, vol. 11, no. 4, pp. 363–375, 1992.

- Y. Nakamura, K. Yamane, I. Suzuki, and Y. Fujita, "Dynamic computation of musculo-skeletal human model based on efficient algorithm for closed kinematic chains," in Proc. of the 2nd Int. Symp. on Adaptive Motion of Animals and Machines, Kyoto, Japan, March 2003.

- Y. Nakamura, K. Yamane, Y. Fujita, and I. Suzuki, "Somatosensory computation for man-machine interface from motion-capture data and musculoskeletal human model," IEEE Transactions on Robotics, vol. 21, no. 1, pp. 58–66, Feb. 2005. - Pressé C. and Gautier M., "New criteria of exciting trajectories for robot identification," in Proc. IEEE Int. Conf. on Robotics

and Automation, Atlanta, 1993, pp. 907–912. - J. Swevers, C. Ganseman, D. Bilgin, J. De Schutter, and H. Van Brussel, "Optimal robot excitation and identification," IEEE Trans. on Robotics and Automation, vol. 13, no. 5, pp. 730–740, 1997.

Cross-validation with a bending motion

- T. Sugihara and Y. Nakamura, "Balanced micro/macro contact model for forward dynamics of rigid multibody," in Proc. of the IEEE Int. Conf on Robotics and Automation, May 2006, pp. 1880–1885.

Application to Humanoid Robots

Knowledge of the robot inertial parameters crucial data to do simulation and control of robot dynamics. Robot manufacturers and designers often give inertial parameter values obtained by CAD software: don't take into account the whole actuators and sensors information Identification of the system dynamics thus expressly required.

Conventionnal methods based on knowledge of all joints informations: joint angle, joint torque... Humanoid robot not always equipped with torque sensors. But have contact force-sensors.

HOMs

Proposed method based on contact force measurement: - Using the property of the dynamic model by using the base-link equations only.

Application to Human

Identification also a solution to measure dynamics in-vivo.

Knowledge of dynamics of human mandátory for simulations of body

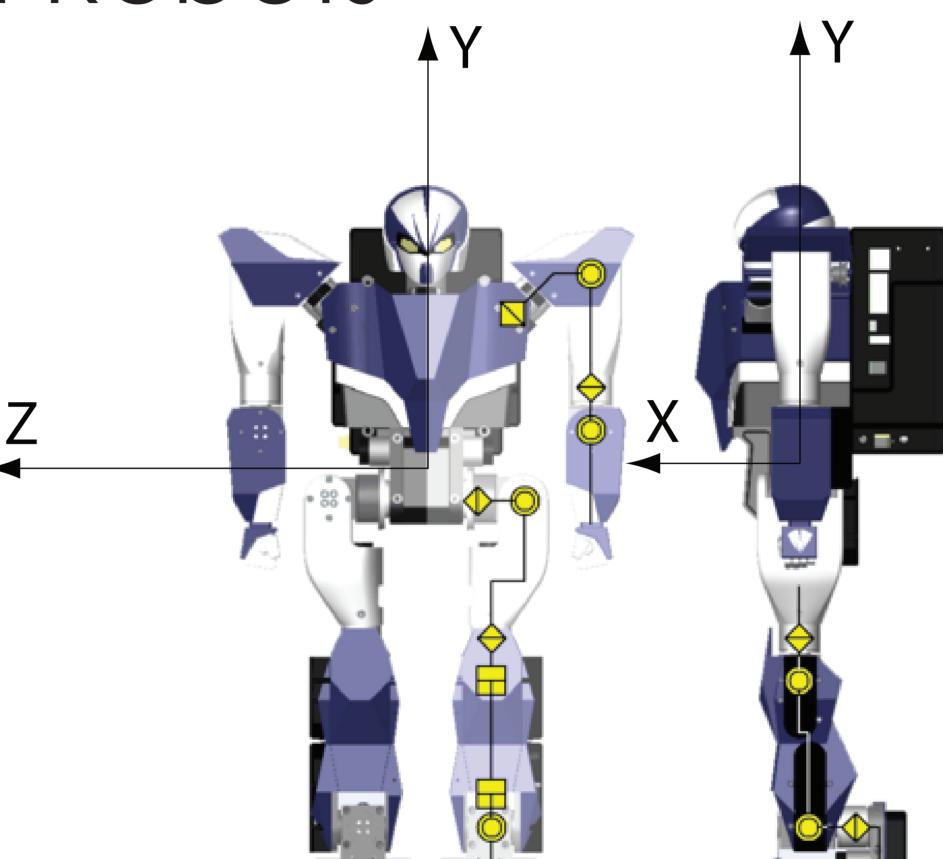
motions, support of medical diagnosis, monitoring of body physical

Based on similar methodology as for humanoid robots, extended to

Instead of sensors, joint angles provided by motion cature data and computation of inverse kinematics making use of a skeletal model.

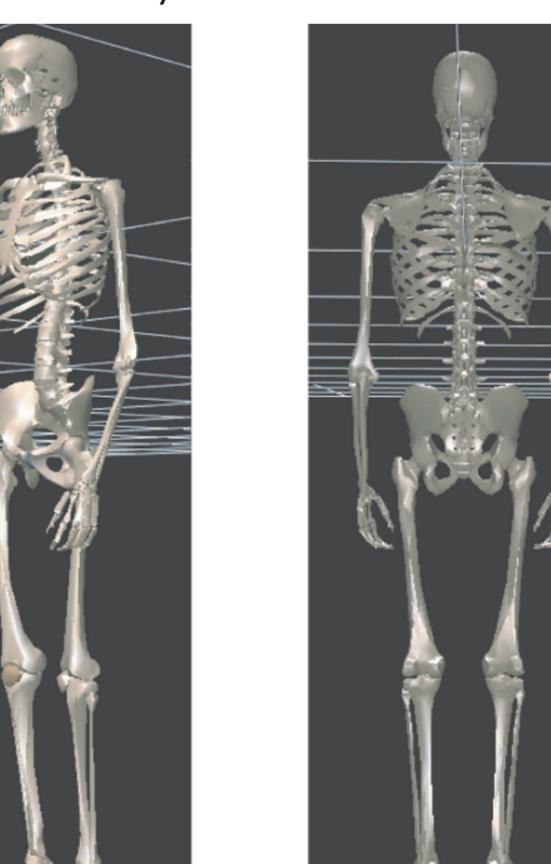
convenient, noninvasive, painless way to measure motion, assures interaction-free measurement between subject and measuring system,

- Required data are limited to joint angles, external forces, and generalized coordinates of the base-link.



Skeletal model of human body

Identifiability of the vector of base parameter with the upper system only has been proven



MOTIONS USED FOR IDENTIFICATION 128 parameters to estimate for the whole body Exciting trajectories must be natural and painléss. Several motions recorded to excite all body parts:

walk, side walk, body bending, movements of the arms, movements of the trunk... Most exciting motions chosen for identification (according to the

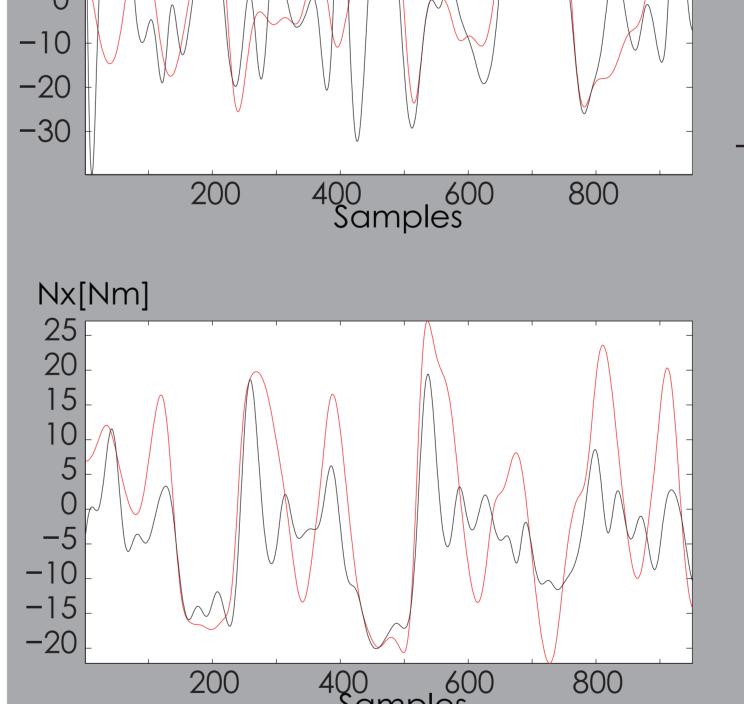
condition number of the regressor).
Remaining motions used for cross-validations.

EXPERIMENTAL SET-UP

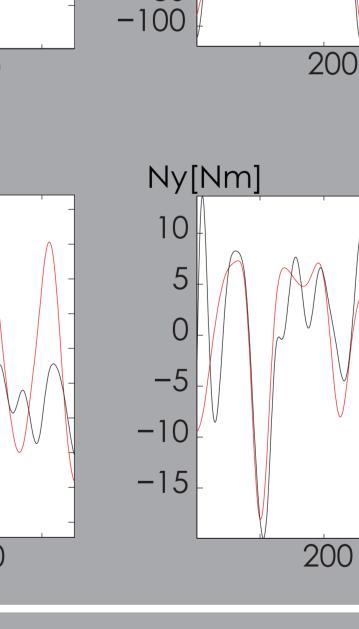
Candidate equipped with 35 optical markers at define atanomical points Execute motions in the motion capture studio, on top of force-plates to measure the 6 components of the contact forces.

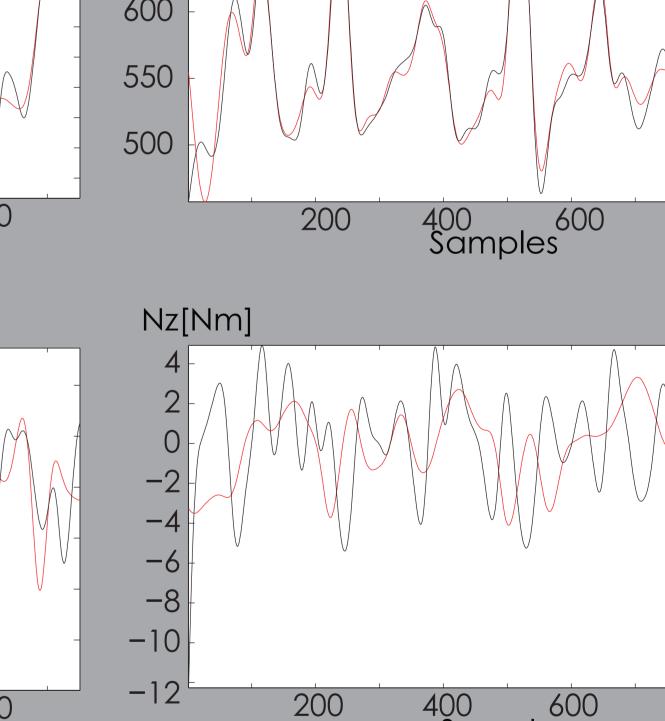


Motion capturing



Cross-validation with a side walk motion





Dr. Gentiane Venture

Application to Human to Support the Diagnosis of Neuromuscular Diseases

Motion capturing advantages:

allow to perform all kind of motions.

Neurological disorders: slowly progressive, degenerative diseases. Affected persons experience various symptoms such as trembling, muscle rigidity, slowed motion, difficulty in walking, problems with body balance and

Outcome assessments of neurological disorders partly relies on the qualitative clinical rating of symptoms: bradykinesia, tremor, and rigidity using ráting scales... Objective quantification tools highly required, apparatus proposed so far too expensive, too complex and required too much time to be used in a clinical setting.

Clinical diagnosis based on patient medical history, observations of symptoms, neurologic examination: - passive tests : patient not moving (no contraction of muscles) but movements induced by the PT. - **semi-active** tests: patient asked to perform lower-body motions resulting in upper-body passive motions. active tests: patient performs full body active motion.

Proposed Constraint-free method

Capturing motions during the clinical diagnosis and identifying joints parameters with constraint-free passive or semi-active motions.

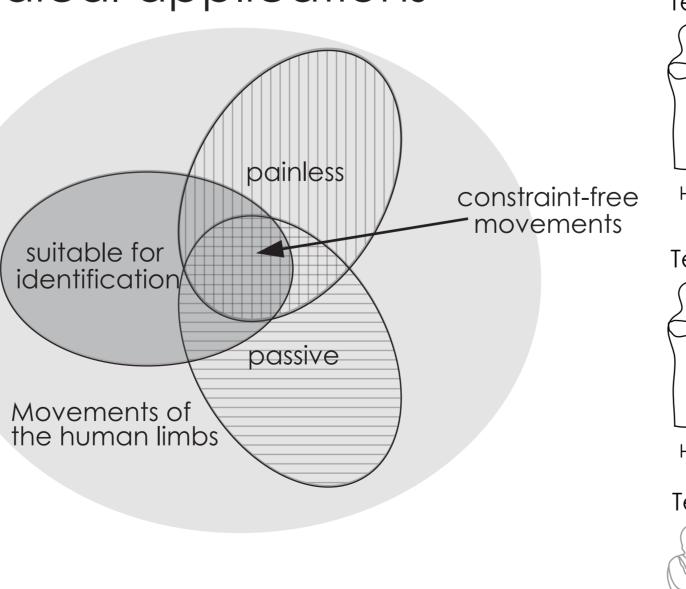
Features and advantages :

- Use of a very detailed rigid-body model to allow to use all kind of motions.

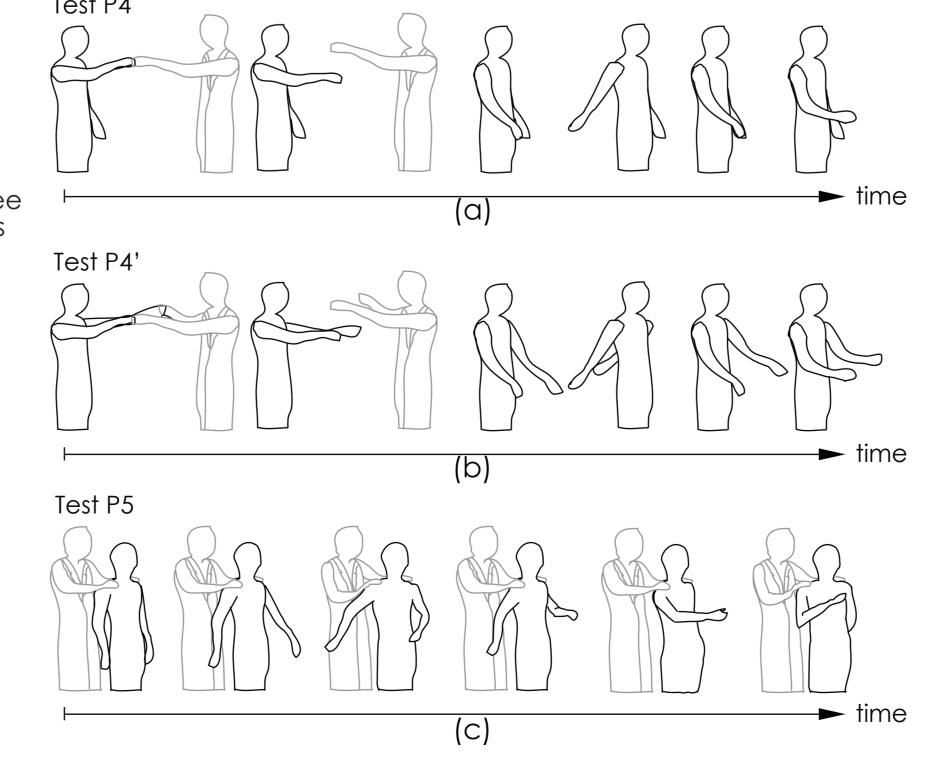
- Roll-out easy, positioning of markers over anatomical points robust and fast. - Capture performed during the normal clinical diagnosis

allowing the PT to perform simultaneously his visual rating. - Non-invasive, non-harrowing and painless. - Simultaneous multi-joint estimation.

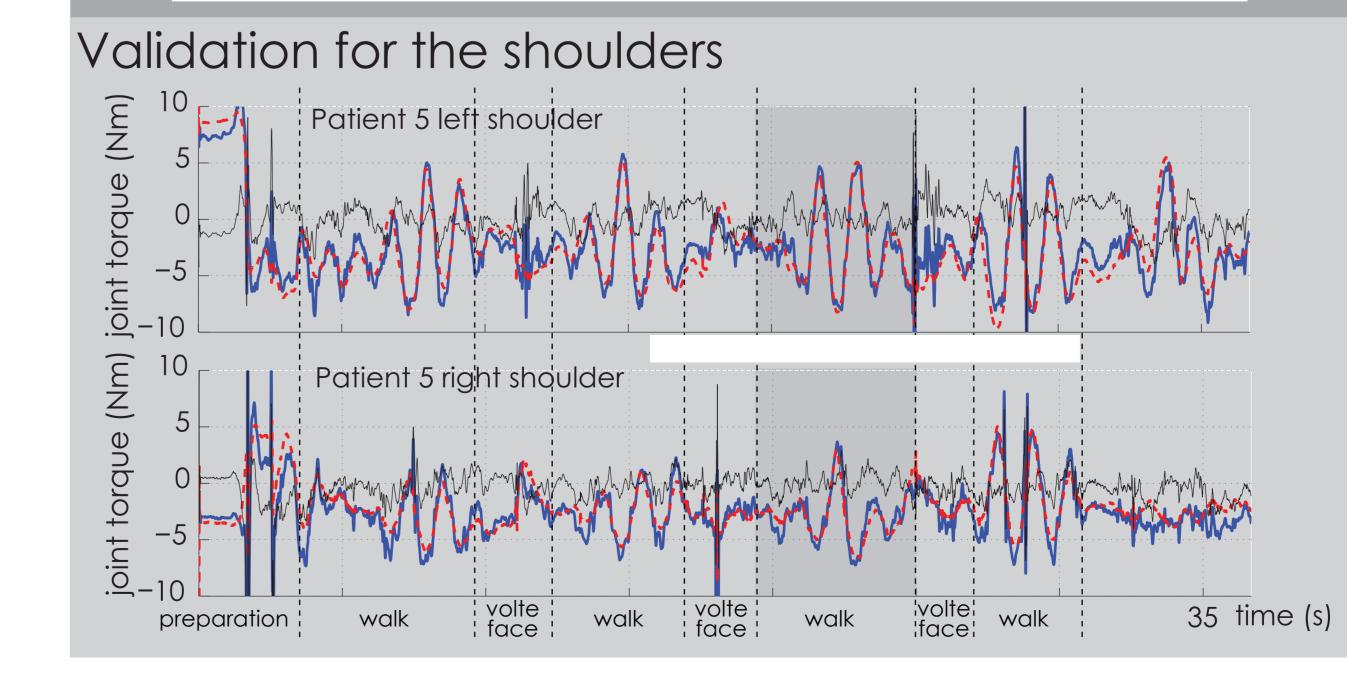
medical applications



Type of motion required to Passive tests used for identification during identify joint dynamics for clinical diagnosis of neuromuscular diseases



Modelling of joint passive visco-elastic properties $oldsymbol{ au} = oldsymbol{\Gamma} + oldsymbol{Q} = oldsymbol{H}\left(oldsymbol{q}, oldsymbol{\dot{q}}, oldsymbol{\ddot{q}}, oldsymbol{I}_P ight) + oldsymbol{ au}^{vef}$ $Kq^2 + kq + h\dot{q} + fsign(\dot{q})$



Patients discrimination according to estimated shoulders stiffness

