Robotics 2

Introduction

Prof. Alessandro De Luca

Dipartimento di Ingegneria Informatica
Automatica e Gestionale Antonio Ruberti

Sapienza
Università di Roma

Robotics 2 – 2019/20

- second semester
  - Monday, February 24 – Wednesday, May 27, 2020
- courses of study
  - Master in Artificial Intelligence and Robotics
  - Master in Control Engineering
- credits: 6
  - ~60 h of lectures, 90 h of individual study (1 ECTS = 25 h work)
- classes
  - Monday 08:00-10:00 (room B2, Via Ariosto 25)
  - Wednesday 14:00-17:00 (room B2, Via Ariosto 25)
- video recordings of the course
  - each lecture will be available soon after in the **Robotics 2 playlist** on the Video DIAG – Sapienza YouTube channel

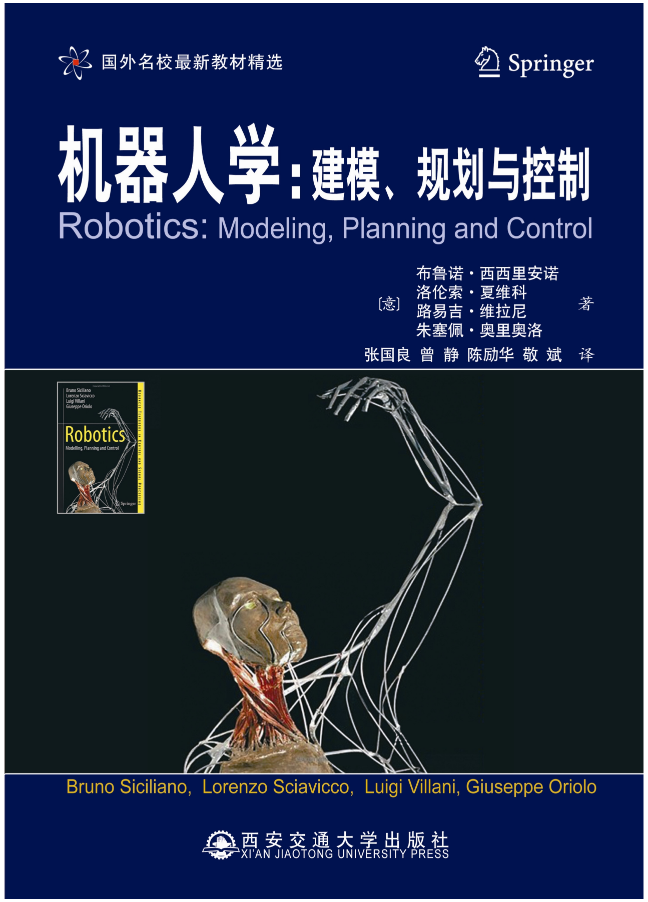
General information

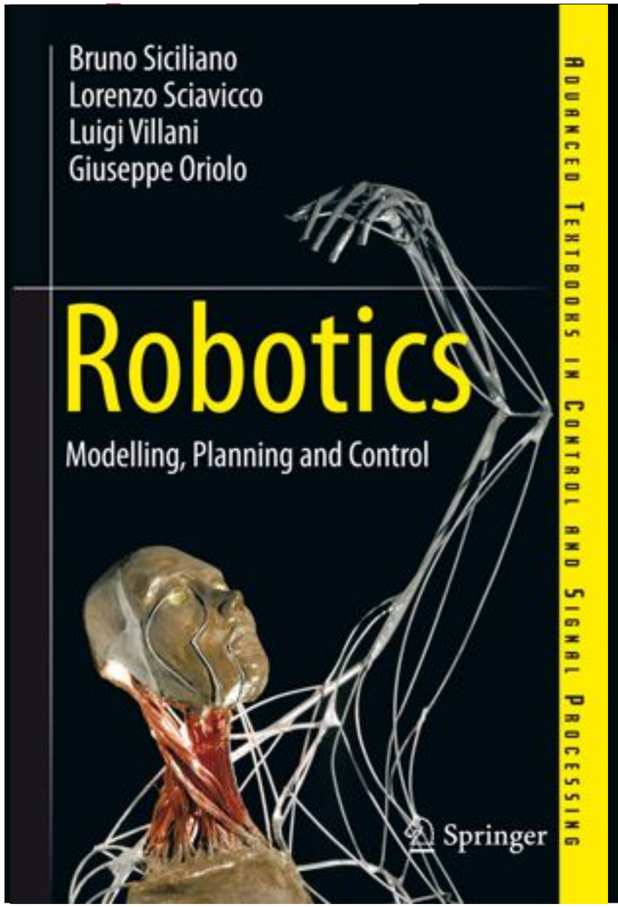
- prerequisites
  - Robotics 1 as prerequisite (see www.diag.uniroma1.it/deluca/rob1_en.php)
- aims
  - advanced kinematics & dynamic analysis of robot manipulators
  - design of sensory feedback control laws for free motion and interaction tasks
- textbook
  - B. Siciliano, L. Sciavicco, L. Villani, G. Oriolo: *Robotics: Modelling, Planning and Control*, 3rd Edition, Springer, 2009
- related courses
  - Autonomous and Mobile Robotics: first semester, 6 credits
  - Elective in Robotics: whole year, 12 credits (four modules)

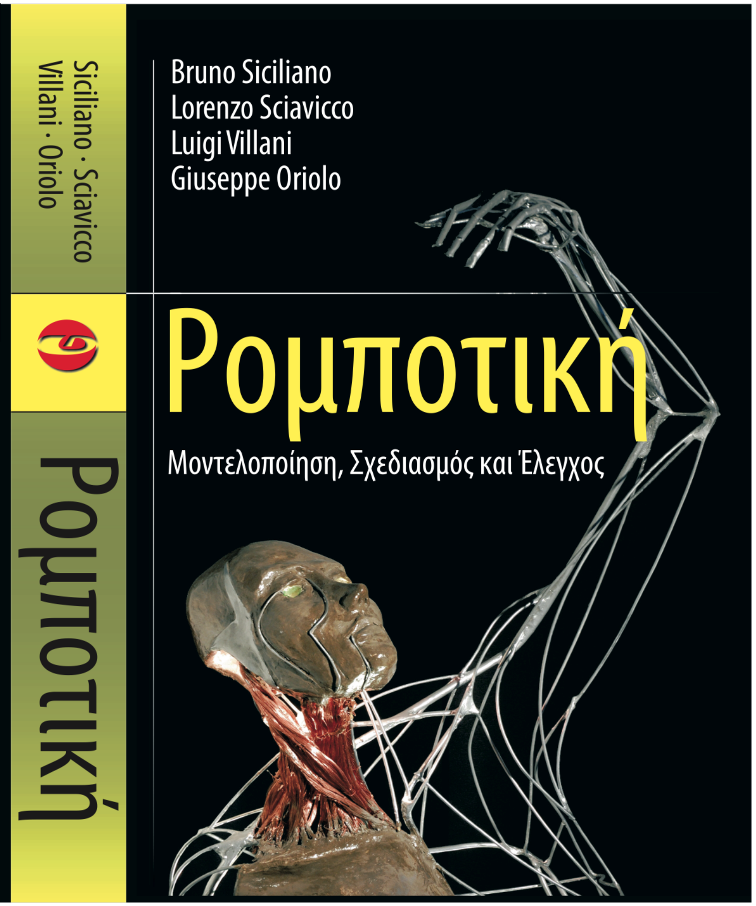
    or Control Problems in Robotics: 6 credits (two out of four modules)
  - Medical Robotics: second semester, 6 credits

An international textbook...

B. Siciliano, L. Sciavicco, L. Villani, G. Oriolo: *Robotics: Modelling, Planning and Control*, 3rd Edition, Springer, 2009







Robotics

- algorithms for robotics*
  - process **inputs from sensors** that provide noisy and partial data
  - build **geometric and physical models** of the robot and the world
  - **plan high- and low-level actions** at different time horizons
  - **execute these actions on actuators** with uncertainty/limited precision
- design & analysis of robot algorithms raise a unique combination of questions from many fields
  - **control theory**
  - computational geometry and topology
  - **geometrical and physical modeling**
  - reasoning under uncertainty
  - probabilistic algorithms and game theory
  - theoretical computer science

* = from intro to WAFR 2016

Program - 1

all on fixed-base robot manipulators!

- advanced kinematics
  - kinematic calibration
  - kinematic redundancy and related control methods
- dynamic modeling of manipulators
  - direct and inverse dynamics
  - Euler-Lagrange formulation
  - Newton-Euler formulation
  - properties of the dynamic model
  - identification of dynamic parameters
  - inclusion of flexibility at the joints
  - inclusion of geometric constraints

Program - 2

- design of feedback control laws
  - free motion tasks
    - set-point regulation
      - PD with gravity cancellation or compensation
      - PID or saturated PID
      - iterative learning
    - trajectory tracking
      - feedback linearization and input-output decoupling
      - passivity-based control
      - adaptive (and robust) control
  - interaction tasks with the environment
    - compliance control
    - impedance control
    - hybrid force/velocity control

Program - 3

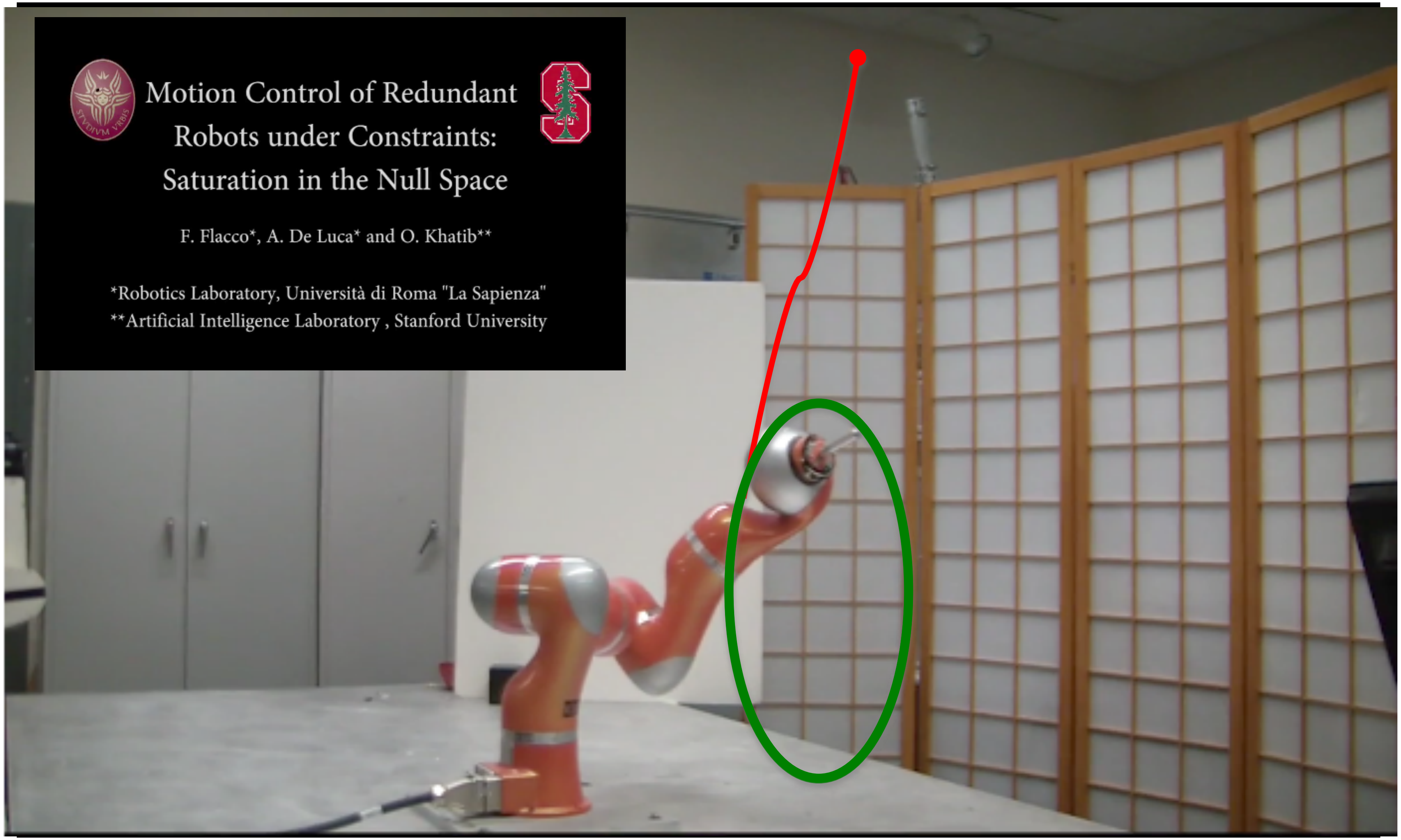
- exteroceptive feedback control laws
  - image- and position-based visual servoing
    - kinematic treatment
- research-oriented seminars
  - diagnosis of robot actuator faults
  - physical Human-Robot Interaction (pHRI)
    - safety: sensorless collision detection and robot reaction
    - coexistence: collision avoidance while sharing workspace
    - collaboration: intentional exchange of contact forces
- simulation tools
  - Matlab/Simulink
  - CoppeliaSim (was V-REP)

Sneak preview of videos follows ...

- kinematic redundancy and related control methods
- robot dynamic modeling and identification
- interaction with the environment: force and motion control
- motion control in the presence of joint flexibility or variable stiffness actuation
- safe physical human-robot interaction & collaboration

Kinematic/dynamic control and redundancy

SNS algorithm handles hard bounds on robot motion

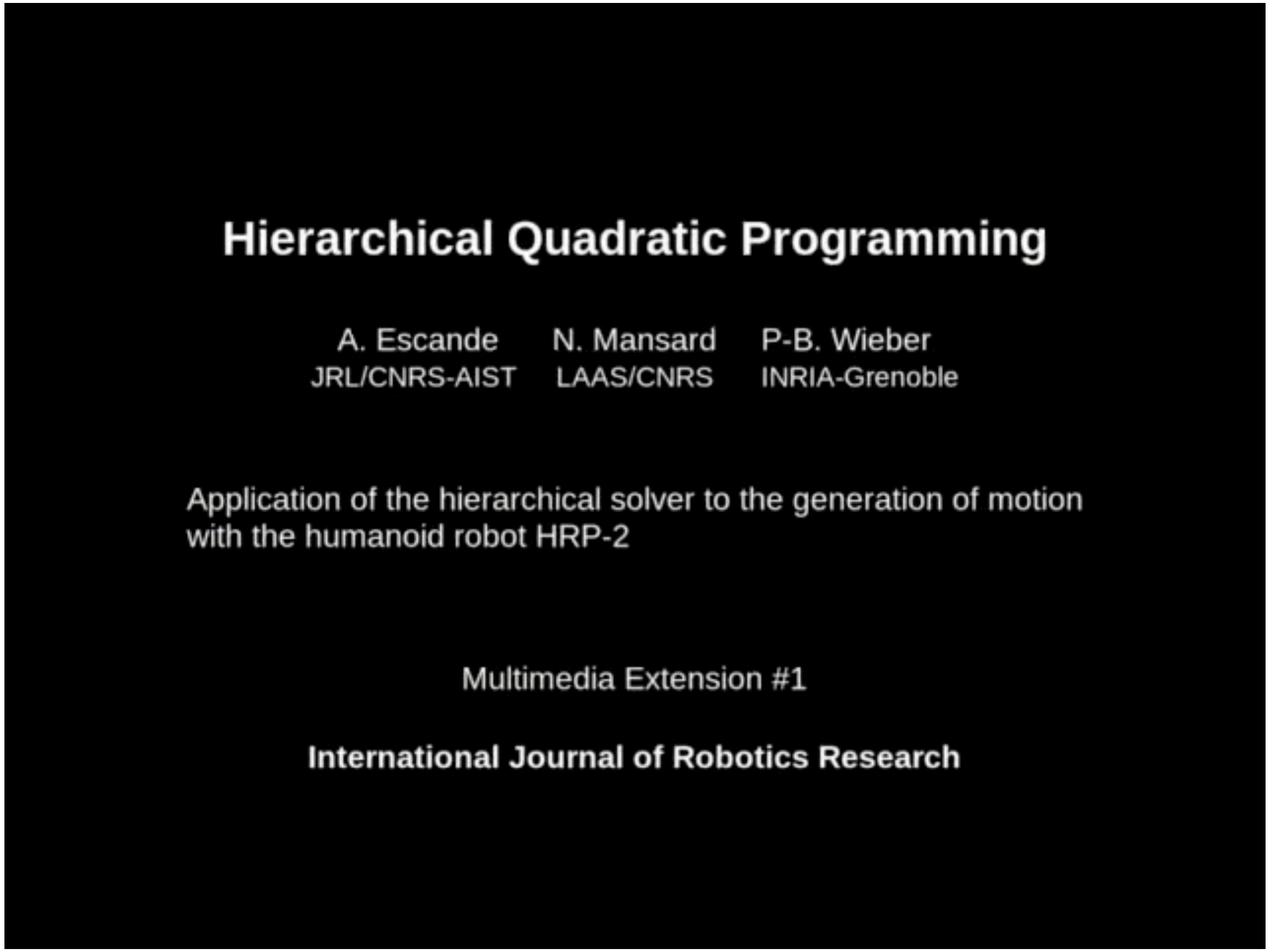


KUKA LWR4 robot — video DIAG Sapienza/Stanford, IEEE ICRA 2012

Kinematic control and redundancy

(standing) HRP-2 humanoid robot

video @LAAS/CNRS Toulouse



HQP approach for multiple equality and inequality tasks with priorities

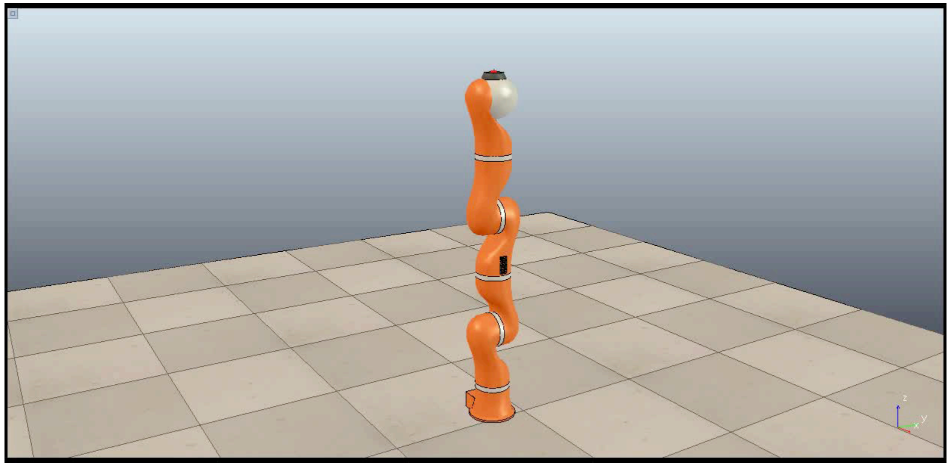
Dynamic modeling and identification

data acquisition
for identification

2 videos ICRA 2014 @DIAG Robotics Lab

model validation
by torque prediction

KUKA LWR4+ robot
with joint torque
sensing



dynamic
simulation
with V-REP

video

Dynamic modeling and identification

e.g., linear parametrization of gravity term in robot dynamic model

$$\boldsymbol{g}(\boldsymbol{q}) = \boldsymbol{Y}_g(\boldsymbol{q})\boldsymbol{\pi}_g$$

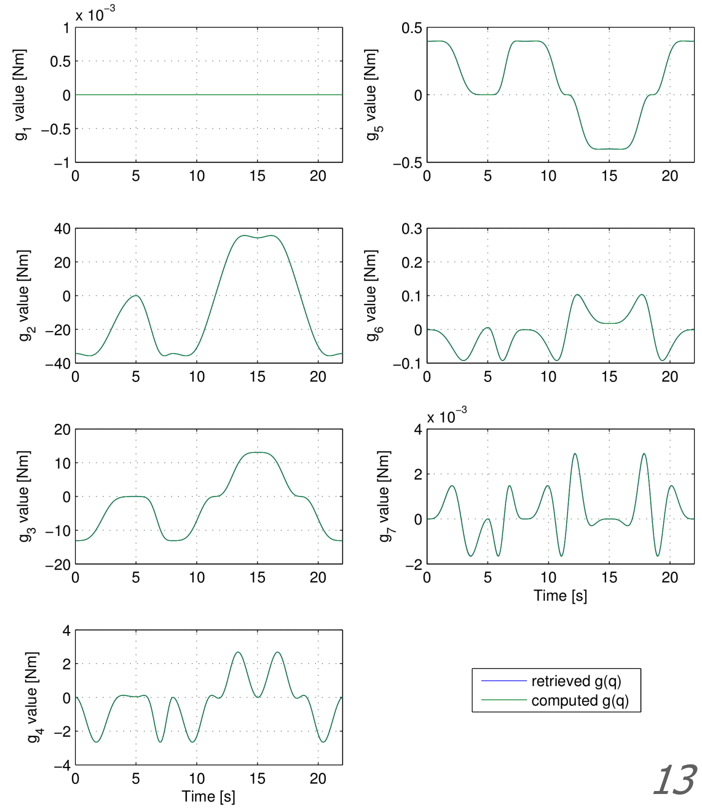
$$\boldsymbol{\pi}_g = \begin{pmatrix} c_{7y}m_7 \\ c_{7x}m_7 \\ c_{6x}m_6 \\ c_{6z}m_6 + c_{7z}m_7 \\ c_{5z}m_5 - c_{6y}m_6 \\ c_{5x}m_5 \\ c_{5y}m_5 + c_{4z}m_4 + d_2(m_5 + m_6 + m_7) \\ c_{4x}m_4 \\ c_{4y}m_4 + c_{3z}m_3 \\ c_{2x}m_2 \\ c_{3x}m_3 \\ c_{2z}m_2 - c_{3y}m_3 + d_1(m_3 + m_4 + m_5 + m_6 + m_7) \end{pmatrix}$$

symbolic expressions of gravity-related dynamic coefficients

$$\hat{\boldsymbol{\pi}}_g = \begin{pmatrix} 9.5457 \times 10^{-4} \\ -2.9826 \times 10^{-4} \\ 8.3524 \times 10^{-4} \\ 0.0286 \\ -0.0407 \\ -6.5637 \times 10^{-4} \\ 1.334 \\ -0.0035 \\ -4.7258 \times 10^{-4} \\ 0.0014 \\ 9.4532 \times 10^{-4} \\ 3.4568 \end{pmatrix}$$

numerical values identified through experiments

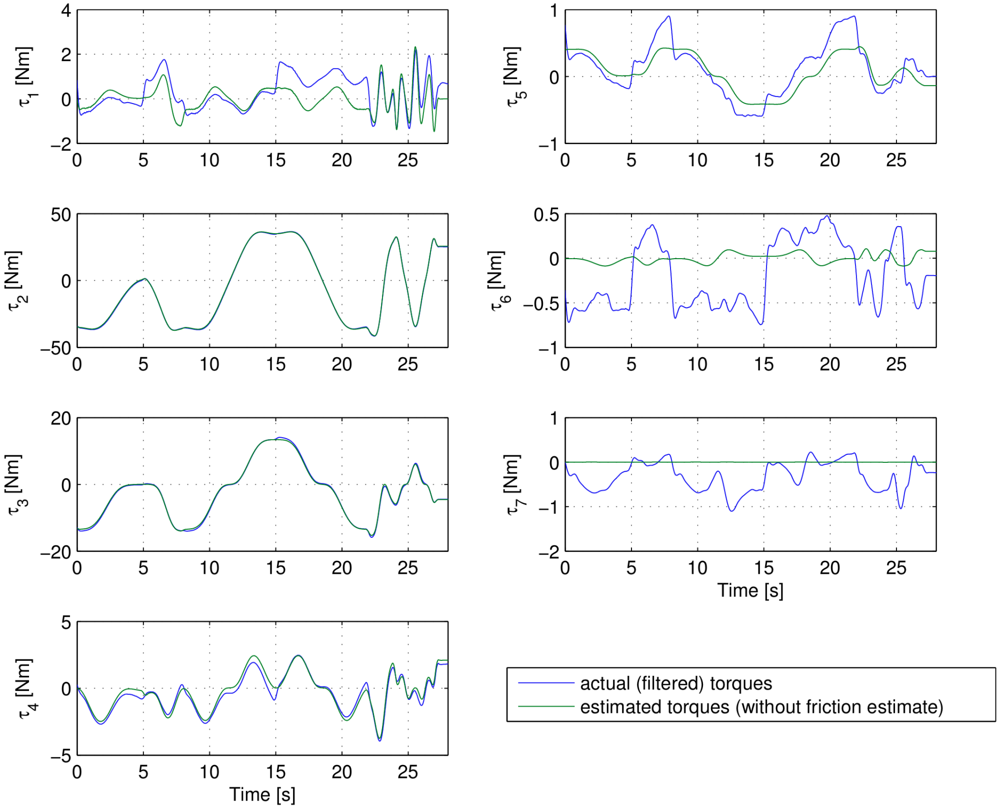
gravity joint torques prediction/evaluation on new validation trajectory

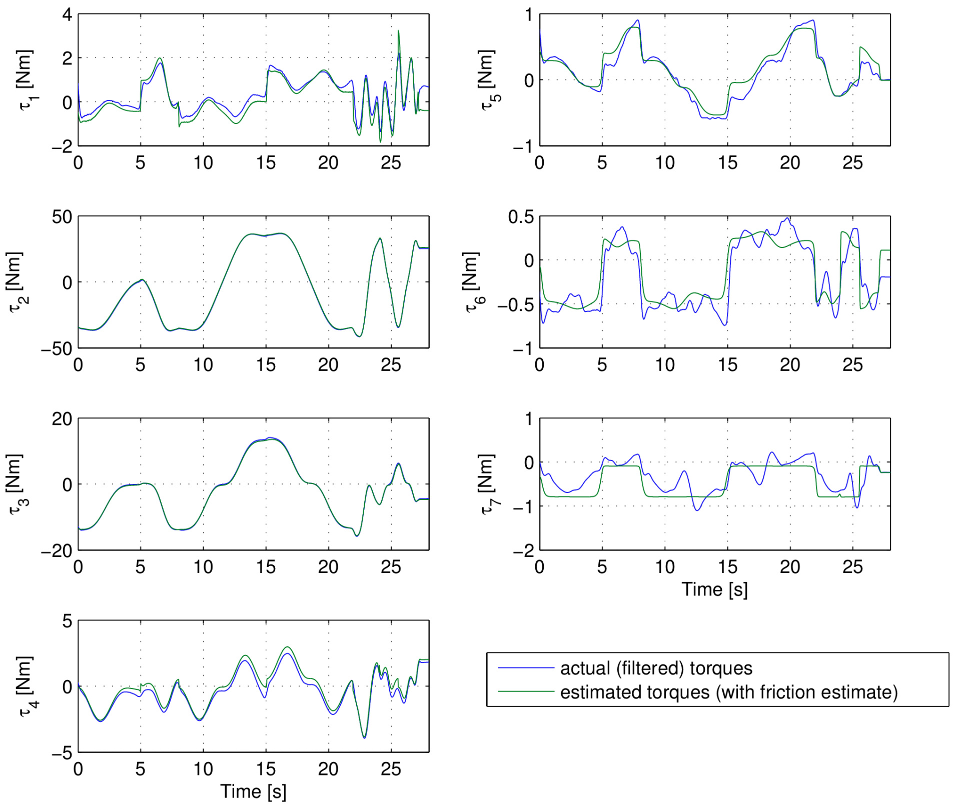


Dynamic modeling and identification

complete dynamic model estimation vs. joint torque sensor measurement

$$\boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} + \boldsymbol{c}(\boldsymbol{q},\dot{\boldsymbol{q}}) + \boldsymbol{g}(\boldsymbol{q}) = \boldsymbol{\tau} - \boldsymbol{\tau}_{friction} \qquad \boldsymbol{\tau}_{meas}$$

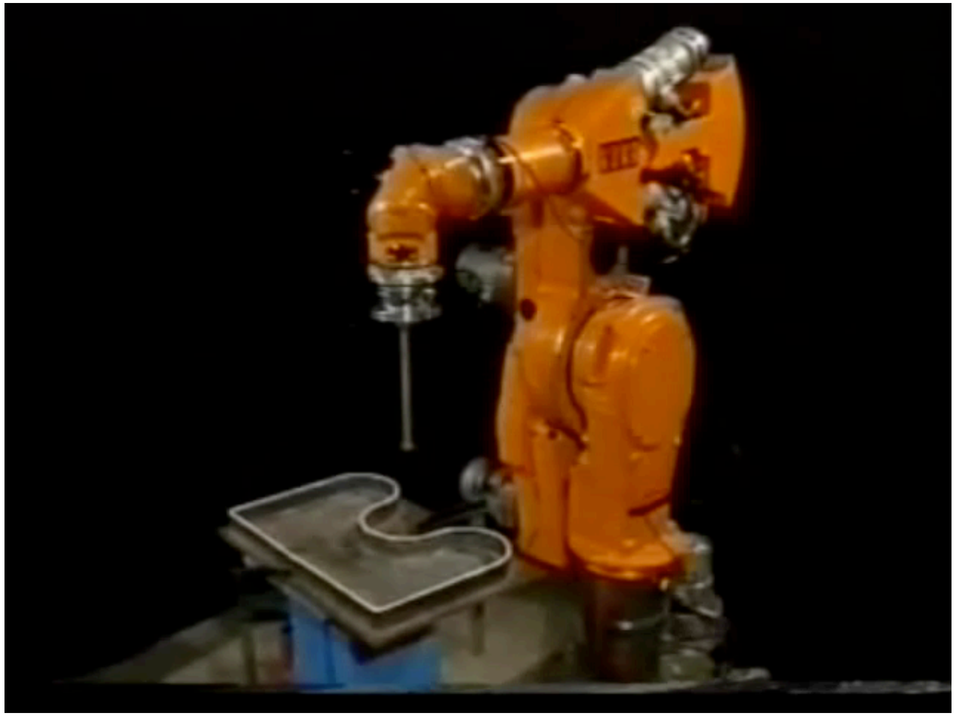




without the use of a joint friction model — including an identified joint friction model

Control of environment interaction

2 video clips extracted from Springer Handbook of Robotics - Multimedia



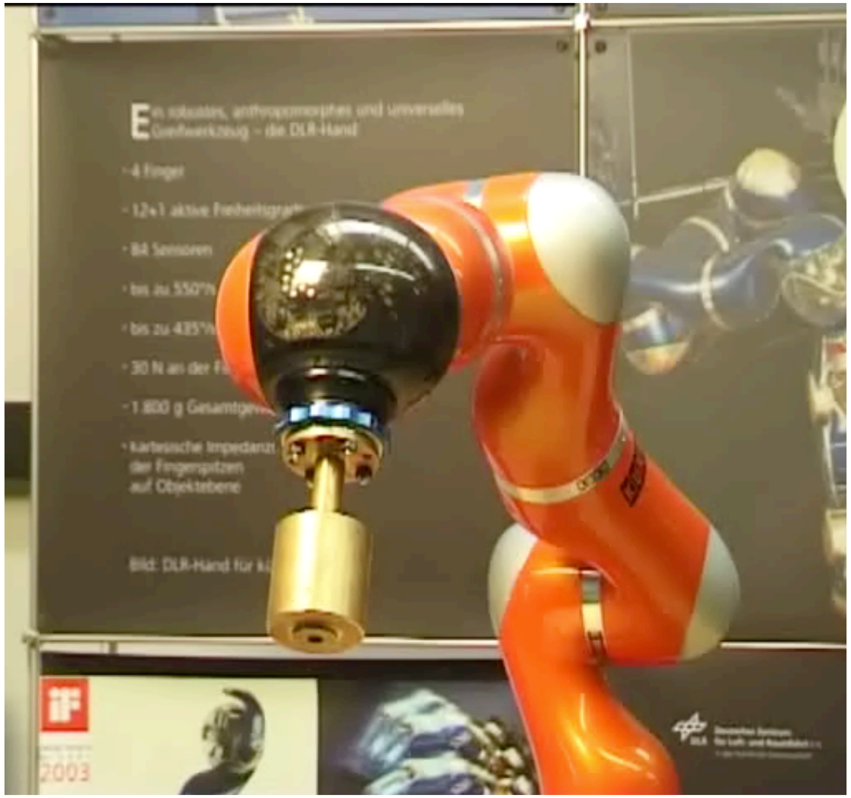
surface contour following

peg-in-hole insertion strategy

De Schutter *et al* @KU Leuven, Belgium (mid '90s)

Motion control

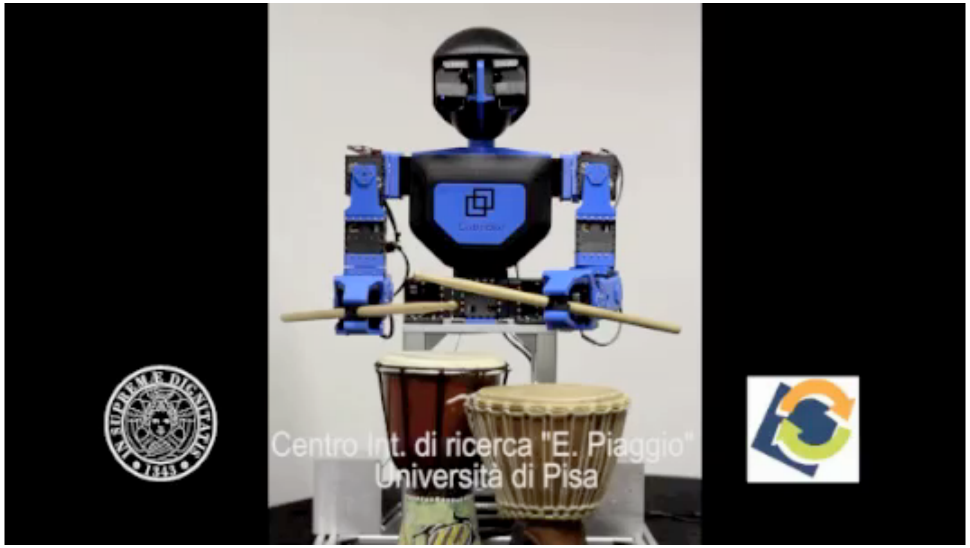
2 videos @DLR München



low-damped oscillations due to flexibility of robot transmissions at the joints (use of Harmonic Drives)

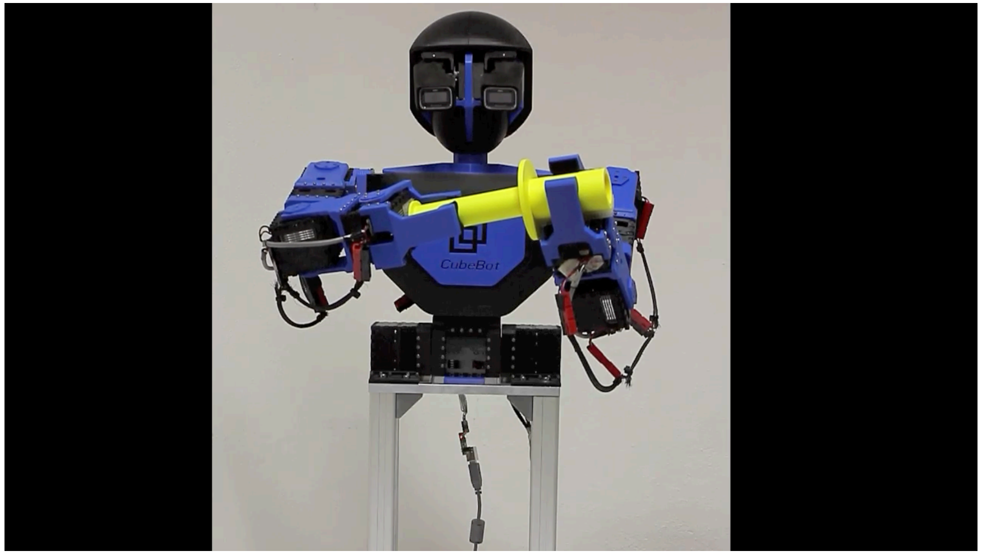
end-effector response to forces with impedance control (behavior selective in directions)

Motion control with VSA



modular, low-cost
qbmove units

3 videos
@University of Pisa



compliant motion with Variable Stiffness Actuators

Sensorless collision detection

2 videos @DLR München

during my sabbatical in 2005-06

master student Sami Haddadin in 2006

residual method to detect collisions: uses robot dynamic model, encoder readings, commanded torques (in case of rigid joints)

NEVER DO THIS!

(unless you're 100% sure of your research results …)

Safe human-robot collaboration

finalist video IROS 2013 @DIAG Robotics Lab

Physical human-robot interaction control

video ICRA 2015 @DIAG Robotics Lab

Some recent EU research projects

- FP7 SAPHARI (2011-15)
  - Safe and Autonomous Physical Human-Aware Robot Interaction
  - www.saphari.eu
- H2020 SYMPLEXITY (2015-18)
  - Symbiotic Human-Robot Solutions for Complex Surface Finishing Operations
  - www.symplexity.eu
- H2020 COMANOID (2015-18)
  - Multi-Contact Collaborative Humanoids in Aircraft Manufacturing
  - comanoid.cnrs.fr

Contacts

- office hours
  - Tuesday 12:00-13:30 c/o A-210, left wing, floor 2, DIAG, Via Ariosto 25
  - .. and/or by email (with some advance)
  - look at the tab "My travel dates" on my web site
- communication by email
  - deluca@diag.uniroma1.it
  - please check/add your address in my Robotics 2 mailing list
- URL: http://www.diag.uniroma1.it/deluca
- video channel: http://www.youtube.com/user/RoboticsLabSapienza
- course material (lecture slides, videos, written exams, …)
  - http://www.diag.uniroma1.it/deluca/rob2_en.html
  - lecture slides ready (*will be updated during the course*)
- registration to exams in infostud (code 1021883)

Exams and Master Thesis

- type of exam
  - classroom midterm test (qualifies for final project)
  - written test + oral part (or final project + oral presentation)
- schedule for academic year 2019/20 (already in infostud)
  - 2 sessions at the end of this semester
    - June 5, 9:00, room B2 and July 15, 9:00, room B2
  - 1 session after the summer break
    - September 11, 9:00, room B2
  - *2 extra sessions **only** for students of previous years, part-time, etc.*
    - in April (between 15 and 21) and in October 2020: times/rooms tbd
  - 2 sessions at the end of the first semester of next year
    - January and February 2021
  - registration in infostud, up to one week before!
- master theses
  - available at DIAG Robotics Lab: http://www.diag.uniroma1.it/labrob