Robotics 1

Introduction

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DIPARTIMENTO DI INGEGNERIA INFORMATICA
AUTOMATICA E GESTIONALE ANTONIO RUBERTI

SAPIENZA
UNIVERSITÀ DI ROMA

Robotics 1 – 2020-21

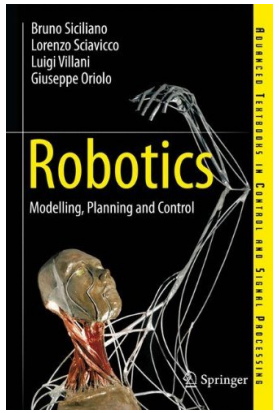
- First semester (11 weeks -- reduced)
  - Tuesday, October 6, 2020 – Friday, December 18, 2020
- Courses of study (with Robotics 1 mandatory or present as optional)
  - Master in Artificial Intelligence and Robotics (MARR)
  - Master in Control Engineering (MCER)
- 6 Credits
  - ~50 hours of lectures, exercises, and midterm test
  - 90 hours of individual study
- Classes (in presence: room B2, DIAG, Via Ariosto 25, online: Zoom)
  - Tuesday 8:00-10:00
  - Friday 8:00-11:00
  - Time zone CEST = UTC+2 until October 24, then CET = UTC+1

Organization and contacts

- Zoom for online
  - topic: Robotics 1 2020-21 (no waiting room if access via uniroma1 email)
- YouTube
  - personal channel, with some recorded videos of the lectures
- Google group
  - join: robotics1_2020-21 (with your uniroma1 email)
- Course website www.diag.uniroma1.it/deluca/rob1_en.php
- Email deluca@diag.uniroma1.it
- Office hours for students
  - every Tuesday 12:00-13:30 (check exceptions)
  - remote: Google Meet https://meet.google.com/chp-fghs-fri
  - in presence: room A-210, floor 2, left wing, DIAG, Via Ariosto 25

Course Materials

- Textbook
  - B. Siciliano, L. Sciavicco, L. Villani, G. Oriolo: *Robotics: Modelling, Planning and Control*, 3rd Edition, Springer, 2009
  - English, Italian, Chinese, or Greek editions



- On course website
  - pdf of lecture slides ready (but with updates during the course)
  - all videos shown in lectures (in zipped folders by block of slides)
  - written exams (most with solutions), papers, extra documents, …
- Video DIAG Channel playlist Robotics 1 with full course of 2014-15
  - 30 (+1 index) videos in classroom (≅ 41h, > 73000 independent views)
- DIAG Robotics Lab Channel with more research videos
  - www.youtube.com/user/RoboticsLabSapienza

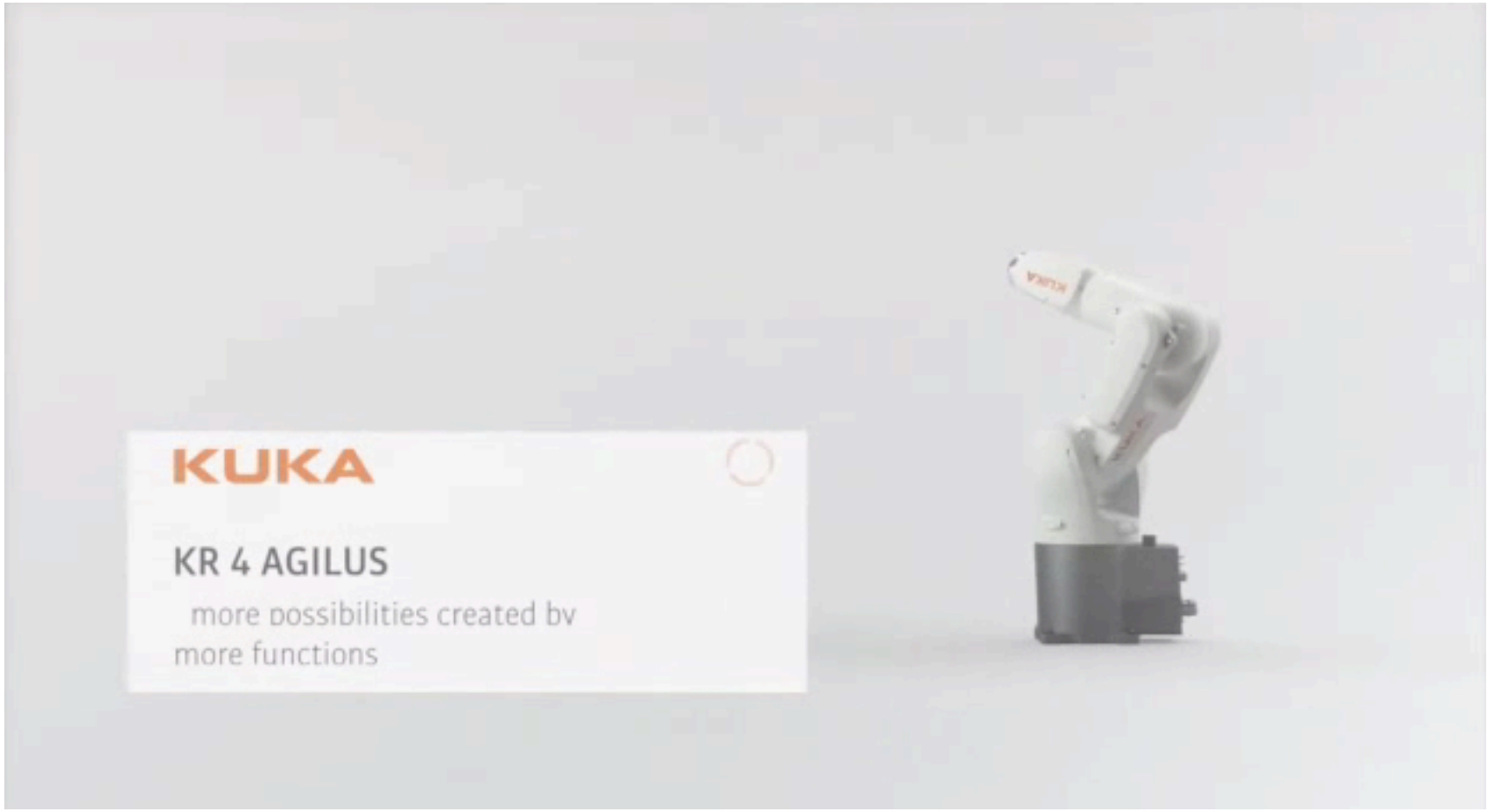
General information

- Prerequisites
  - self-contained course, without special prerequisites
  - elementary knowledge on kinematics, linear algebra, and automatic control is useful
- Aims
  - tools for kinematic analysis of chains of multiple rigid bodies, trajectory planning, and programming of motion tasks for robot manipulators in industrial and service environments
- Other strictly related courses
  - Robotics 2: II semester (of year I), 6 credits
  - Autonomous and Mobile Robotics: I semester (of year II), 6 credits
  - Elective in Robotics (12 credits, MARR) or Control Problems in Robotics (6 credits, MCER): year II, 4 or 2 modules of 3 credits

A robot manipulator

Illustrating typical features of an industrial robot

commercial video



KUKA KR 4 Agilus robot with 6 revolute joints

Programming robot motion

Teaching Cartesian poses and playing them back

video

KUKA LBR iiwa robot with 7 revolute joints

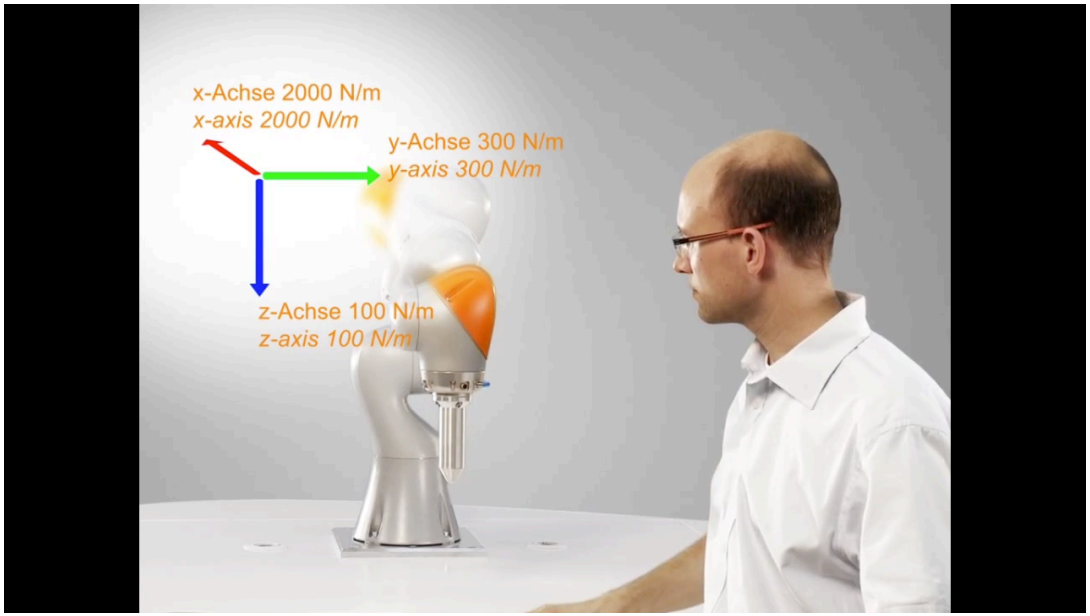
Programming robot motion

Executing nominal trajectories and "complying" with uncertainties

video

Programming robot compliance

Controlled reaction to applied forces/torques at robot end-effector

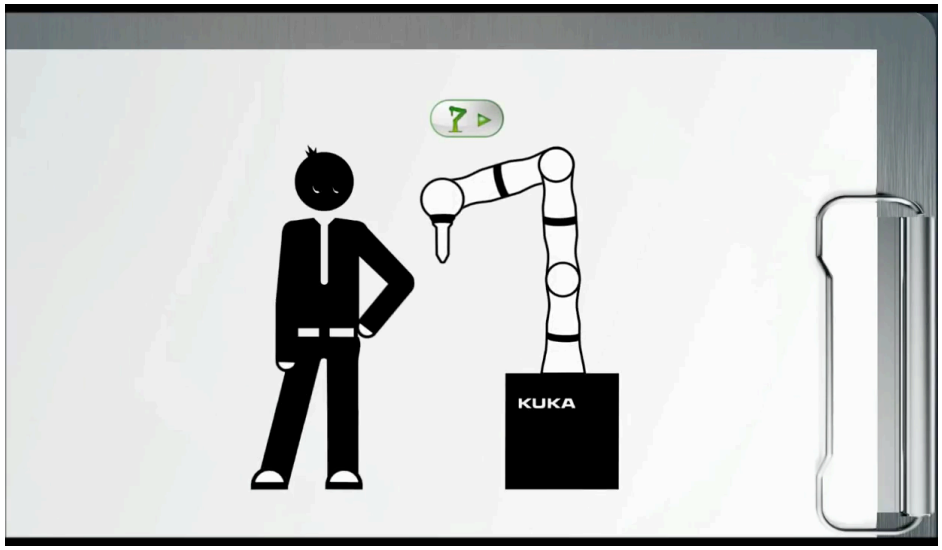


video

video

Programming robot motion

Teaching tasks by demonstration (kinesthetic learning)



sketch of the original idea
— a first need & use of safe physical Human-Robot Interaction (pHRI)

video

video

the working industrial solution

more videos on
KUKA Robotics YouTube Channel

Program

- Introduction
  - Manipulator arms (and few mobile base robots)
  - Industrial and service applications
- Components
  - Mechanical structures
  - Actuators and transmissions
  - Sensors
    - proprioceptive (encoder, tacho)
    - exteroceptive (force/torque, tactile, ultrasound, infrared, laser, vision)
- Kinematic models
  - Minimal representations of orientation
  - Direct and inverse kinematics of robot manipulators
    - Denavit-Hartenberg formalism for frame assignment
  - Differential kinematics: analytic and geometric Jacobians
  - Statics: Transformations of forces
  - Robot singularities

Program (continued)

- Planning of motion trajectories
  - Trajectory planning in the joint space for robot manipulators
  - Trajectory planning in the task/Cartesian space
- Motion control
  - Control system architectures
  - Kinematic control laws (in joint or in task/Cartesian space)
  - Independent joint axis control laws (P, PD, PID)
- Programming and Simulation
  - Programming language for industrial robots (KRL)
  - Use of Matlab/Simulink and CoppeliaSim (V-REP)
  - If feasible, demos with KUKA robots (6-dof KR5; 7-dof LWR4+) and Universal Robots (6-dof UR-10, with non-spherical wrist)

Exams and beyond

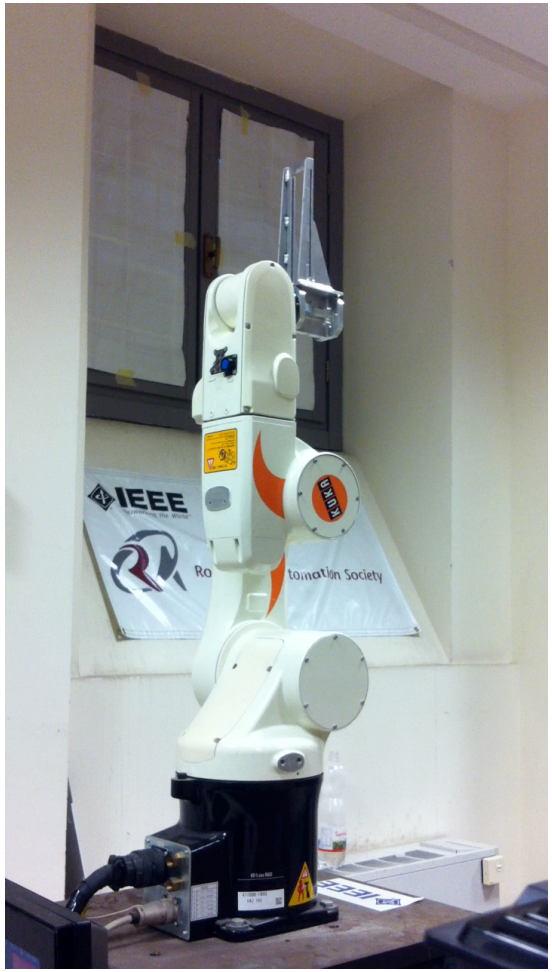
- Type remote midterm test + written exam (+ oral exam, only if needed)
- Schedule of 2020-21 sessions
  - 2 sessions at the end of this semester
    - between January 7 and February 19, 2021
  - 2 sessions at the end of next semester
    - between May 31 and July 23, 2021
  - 1 session after the summer break
    - between September 1 and 17, 2021
  - *2 extra sessions **ONLY** for students of previous years, part-time, ...*
    - March 15–April 21 and October 4–November 5, 2021

will open soon on Infostud check the course website!

- Signing up to exams
  - on Infostud
- Master theses
  - samples available at DIAG Robotics Lab www.diag.uniroma1.it/labrob

Robot manipulators
available at DIAG Robotics Lab (S-218)

video



KUKA KR-5

video

KUKA LWR4+ (lightweight, about 14 kg)

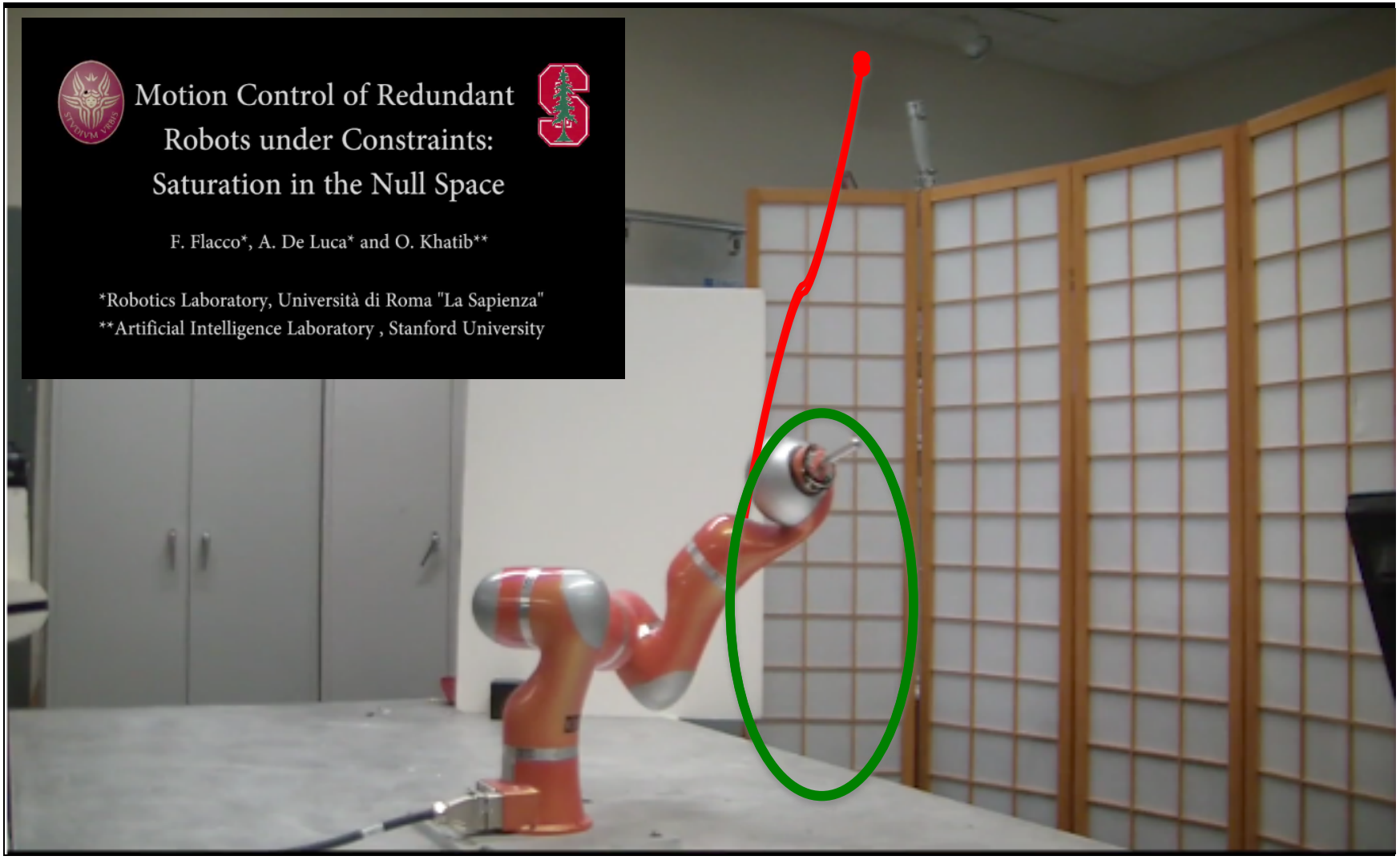
Robot manipulators
available at DIAG Robotics Lab (S-218)

commercial video

upon arrival (July 2016)

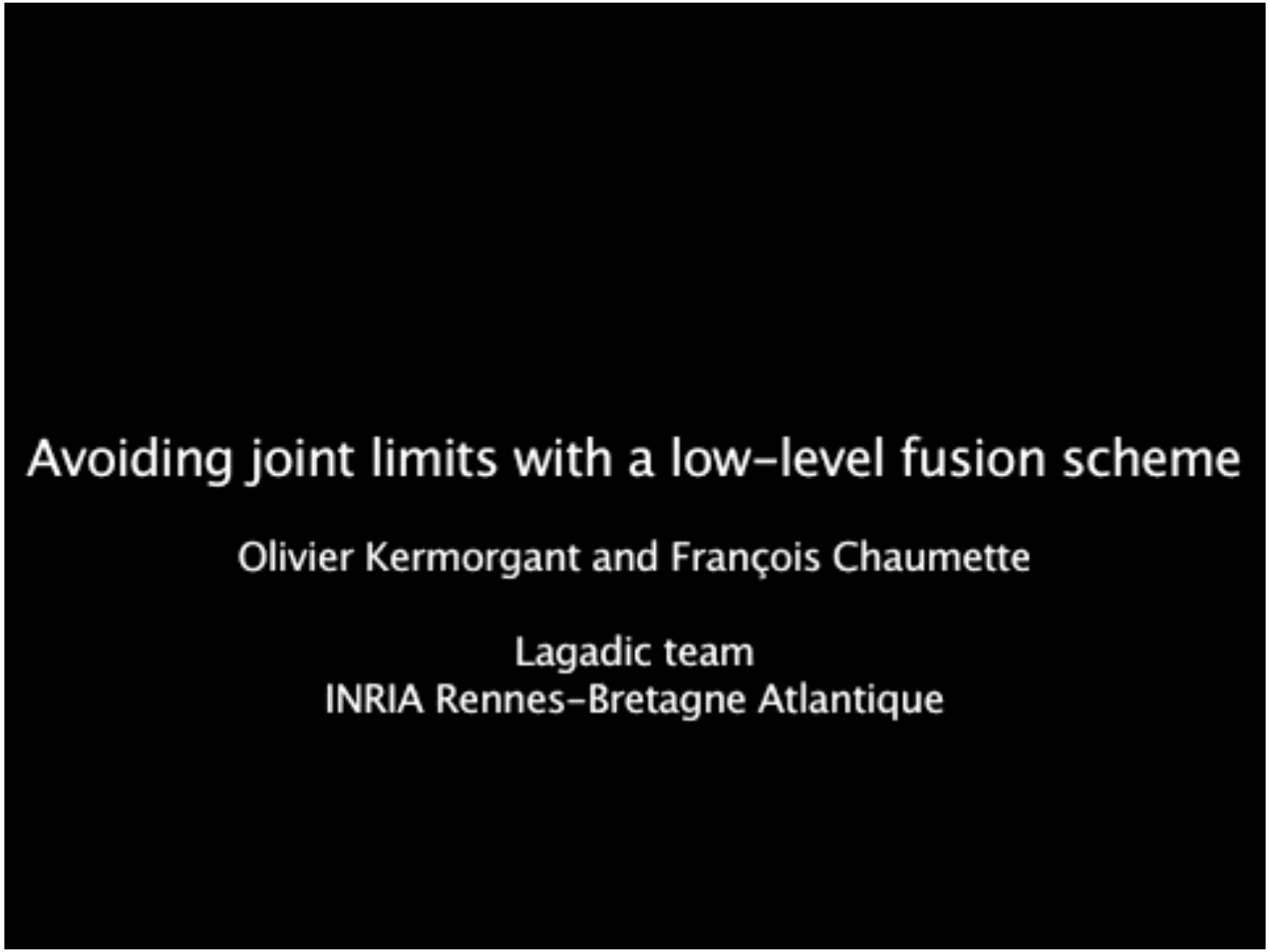
Universal Robots UR-10 (= 10 kg of payload)

Tracking a Cartesian trajectory
with hard position/velocity bounds on robot motion



video DIAG Sapienza/Stanford, IEEE ICRA 2012

Robot control by visual servoing
with limited joint motion range



video INRIA Rennes, IEEE/RSJ IROS 2011

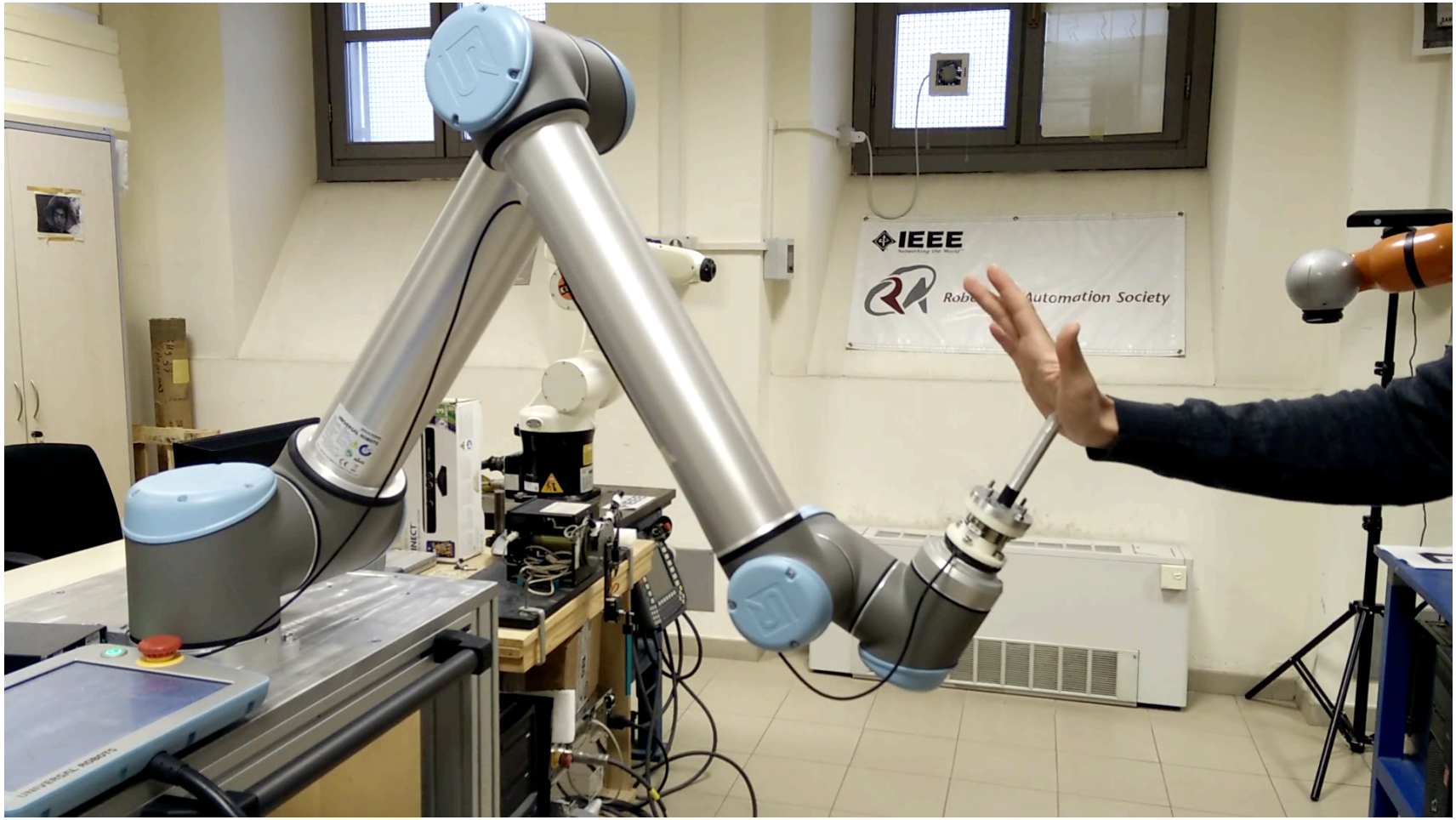
Sensor-based robot control
in dynamic environments (coexistence with human)

video DIAG Sapienza/Stanford, IEEE ICRA 2012

Safe physical human-robot interaction
(sensor-less (!) and on a conventional industrial robot)

video DIAG Sapienza, IEEE ICRA 2013

Human-robot collaboration
(with a real F/T and a "virtual" sensor to distinguish contacts)

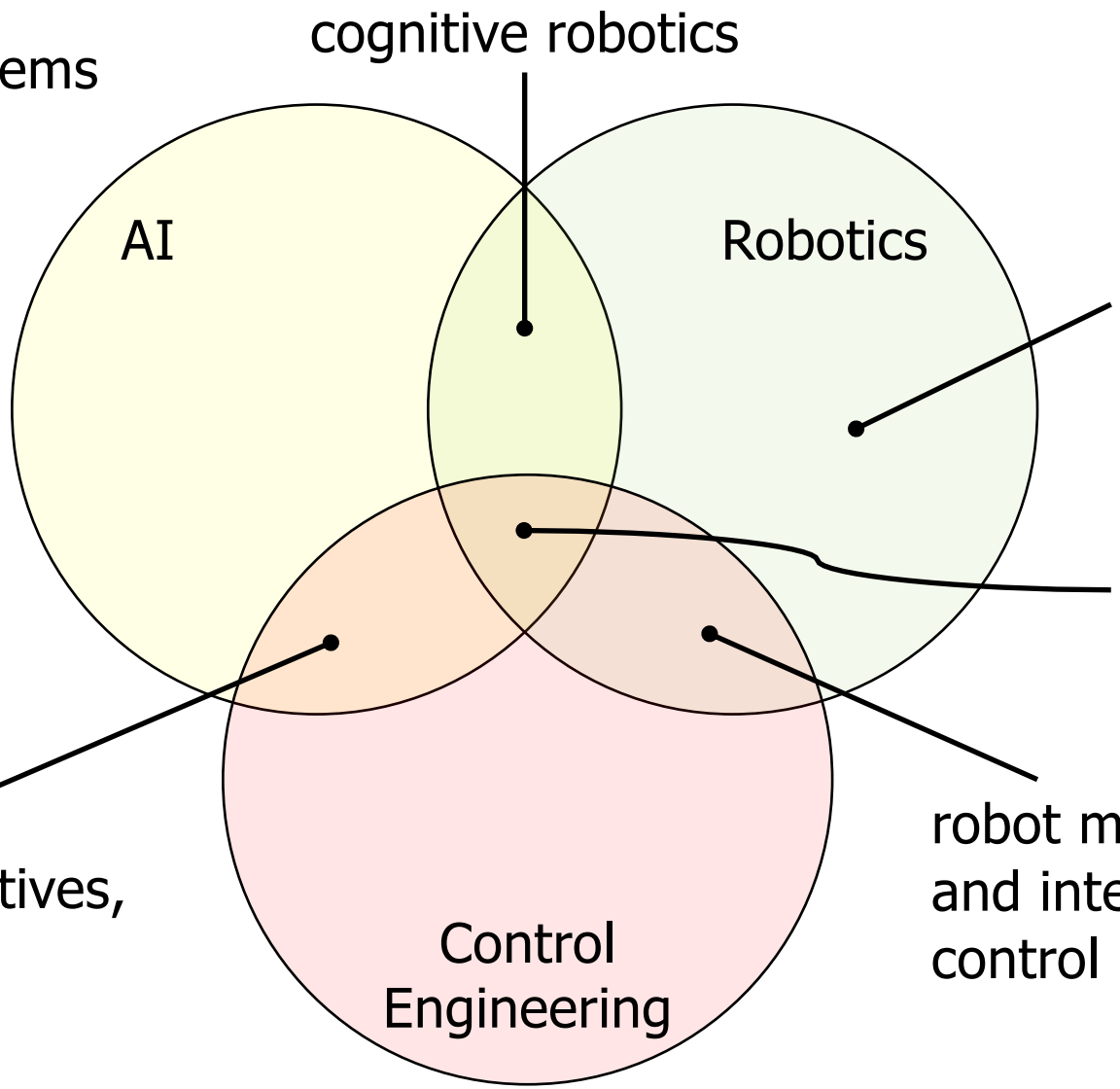


video DIAG Sapienza, J. of Mechatronics, 2018

Next generation of intelligent robots?

Robots =
embodied AI systems

Robotics =
science
of artifacts
intelligently
actuated and
interacting with
the real world



Horizon Europe (2021-27)

https://ai-data-robotics-partnership.eu

Cross-Sectorial AI, Data and Robotics Technology Enablers

Sensing and Perception

Knowledge and Learning

Reasoning and Decision Making

Action and Interaction

Systems, Methodologies, Hardware & Tools

Robotics Deep Dive

Physical Interaction

Physical and Psychological Safety

Actuated Mechanical Structures

Unpredictable and Unknown Environments

Irreversible Actions

4 Market Prioritization in Robotics (from Horizon 2020)

Healthcare

Maintenance and Inspection of Infrastructures

Agri-Food

Agile Production

Specific to Robotics

- hard physical nature of Robotics ("AI embodied")
- wide range of technologies are integrated within robotic systems
- skill mix for success is broader than that for AI or Data alone
- robots are realizations of advanced system-level concepts
  - such as autonomy, control, sensing and programming
- robots are both producers and consumers of data
  - physical model-based approaches, generation of data-driven models
- decision makers and general public need a better understanding of what Robotics is and can achieve, and how it can be deployed
  - Fukushima, Covid-19, ….

AI & Robotics point of views

one of the enabling technologies

… its relations with the other technologies

	Sensing and Perception	Knowledge and Learning	Reasoning and Decision Making	Systems, Hardware, Methodologies and Tools
Action and Interaction	Depends on sensing of motion and mechanical properties Relies on perception for interaction Uses recognition of actions and sequences of interactions in people	Gets semantic knowledge around objects and human actions Gets data on objects and places	Depends on real-time context-aware decision making Trusted decision making	Depends on fast reactive architectures for control Relies on edge-based AI Requires assurance of safe operation and data privacy

Real-time interpretation of multi-modal data

Safe monitoring in human environments

Active exploration strategies

Adaptive decision-making models from sparse data

Planning and re-planning under uncertainty and incomplete knowledge in dynamic environments

Real-time control (distributed/decentralized)

Safe control of physical human-interaction

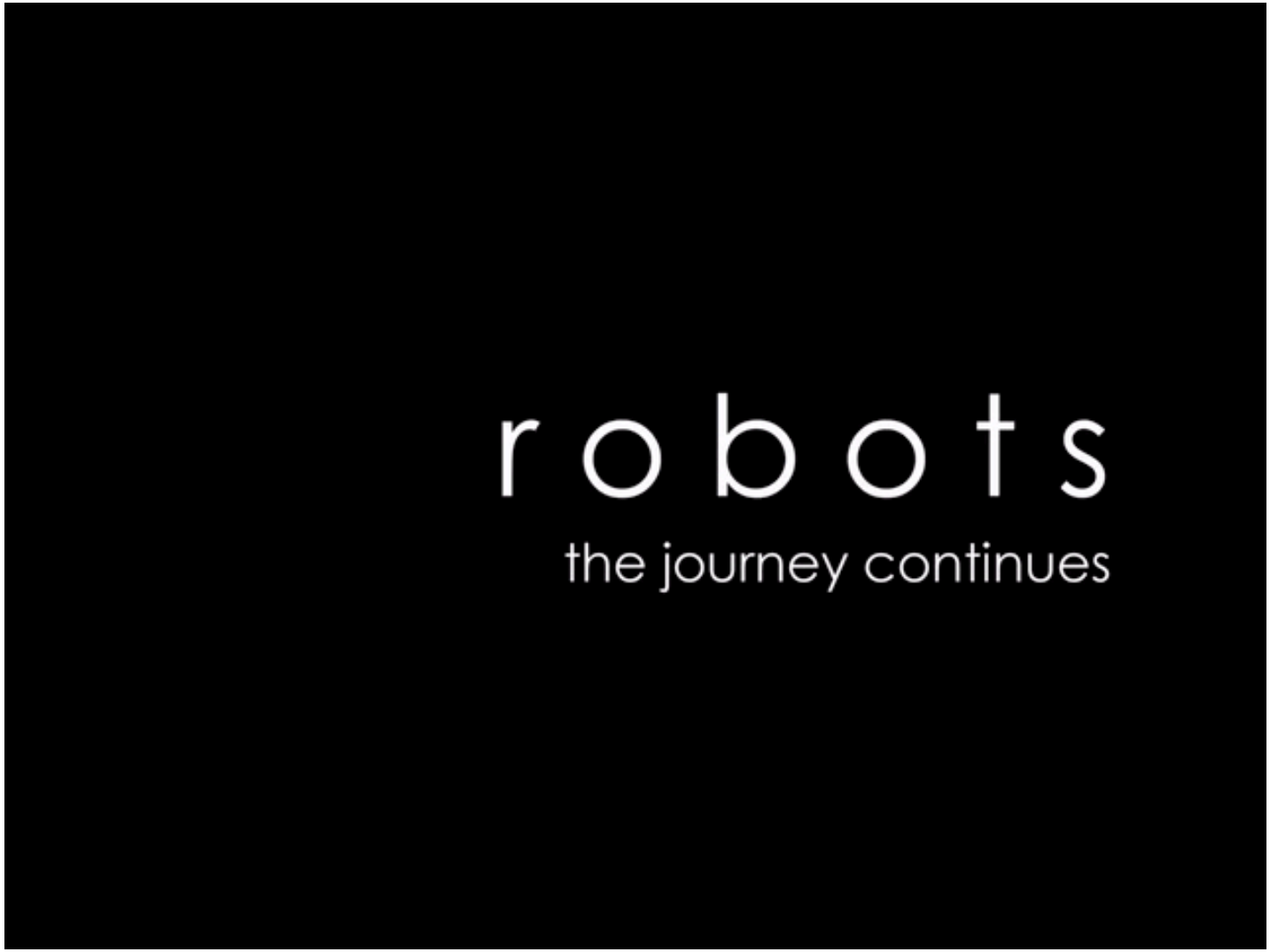
Agility (speed and strength) of collaborative robots

InterAction Technology (lightweight, compliant & soft devices/materials)

Energy-efficient, robust and sustainable design

Robotics around the world...

Springer Handbook of Robotics (2nd Edition, July 2016)



https://vimeo.com/173394878

Preview of Robotics 2 (next semester)

- Advanced kinematics / Robot dynamics
  - Calibration
  - Redundant robots
  - Dynamic modeling: Lagrange and (recursive) Newton-Euler methods
  - Identification of dynamic parameters
- Control techniques
  - Free motion linear and nonlinear feedback control, iterative learning, robust control, adaptive control
  - Constrained motion impedance and hybrid force-velocity control
  - Visual servoing (kinematic approach)
- Special topics
  - Diagnosis and isolation of robot actuator faults
  - Human-robot collision avoidance & detection, with safe robot reaction

Other courses about Robotics and Control

- Autonomous and Mobile Robotics (6 credits), I semester, year 2
  - kinematics, planning, control of wheeled and legged mobile robots
  - motion planning with obstacles, navigation, and exploration
  - Prof. Oriolo www.diag.uniroma1.it/oriolo/amr
- Medical Robotics (6 credits), II semester
  - robot surgical systems, haptics, and more ...
  - Prof. Vendittelli www.diag.uniroma1.it/vendittelli/didattica/mr
- Elective in Robotics (12 credits) or Control Problems in Robotics (6 credits)
  - I-II semesters, starting this semester
  - 4 modules of 3 credits (for CPR, MCER students take 2 modules out of the 4 in EiR)
  - research-related subjects and seminars
  - multiple instructors www.diag.uniroma1.it/vendittelli/EIR
- Robot Programming (lectures, not for credits!)
  - robot programming using C++, ROS, NAO SDK as development frameworks
  - see Prof. Nardi www.diag.uniroma1.it/nardi/Didattica/CAI/robpro-free.html