



Robotics 1

Introduction

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DIPARTIMENTO DI INGEGNERIA INFORMATICA
AUTOMATICA E GESTIONALE ANTONIO RUBERTI



SAPIENZA
UNIVERSITÀ DI ROMA



Robotics 1 – 2025-26

- **First semester**
 - Wednesday, September 24, 2025 – Friday, December 19, 2025
- **Courses of study (those having Robotics 1 mandatory or 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** (**room B2**, DIAG, Via Ariosto 25)
 - Wednesday 15:00-17:00
 - Friday 8:00-11:00

Organization and contacts



all hyperlinks in red
are active in my pdf files

- G-group
 - join [robotics1_2025-26](#)
 - your **full name**, [uniroma1](#) email, [course of study & year \(1,2,...\)](#)
 - please [ask](#) questions & [comment](#) on my replies (everyone will benefit!)
- Email deluca@diag.uniroma1.it (personal or private matters)
- Office hours for students
 - Tuesday [12:00-13:30](#) (check [exceptions](#), e.g., when I'm on [travel](#))
 - in presence: [Room A-210](#), floor 2, left wing, DIAG, Via Ariosto 25
 - remote: [Zoom](#) (or [Meet](#)), see www.diag.uniroma1.it/deluca/Teaching.php



General information

■ Prerequisites

- self-contained course, without special prerequisites
- background knowledge of **kinematics** (of a point, of a single rigid body) and **linear algebra** (vectors and matrices)
- basics on **feedback control** (of linear systems) is useful

■ Aims

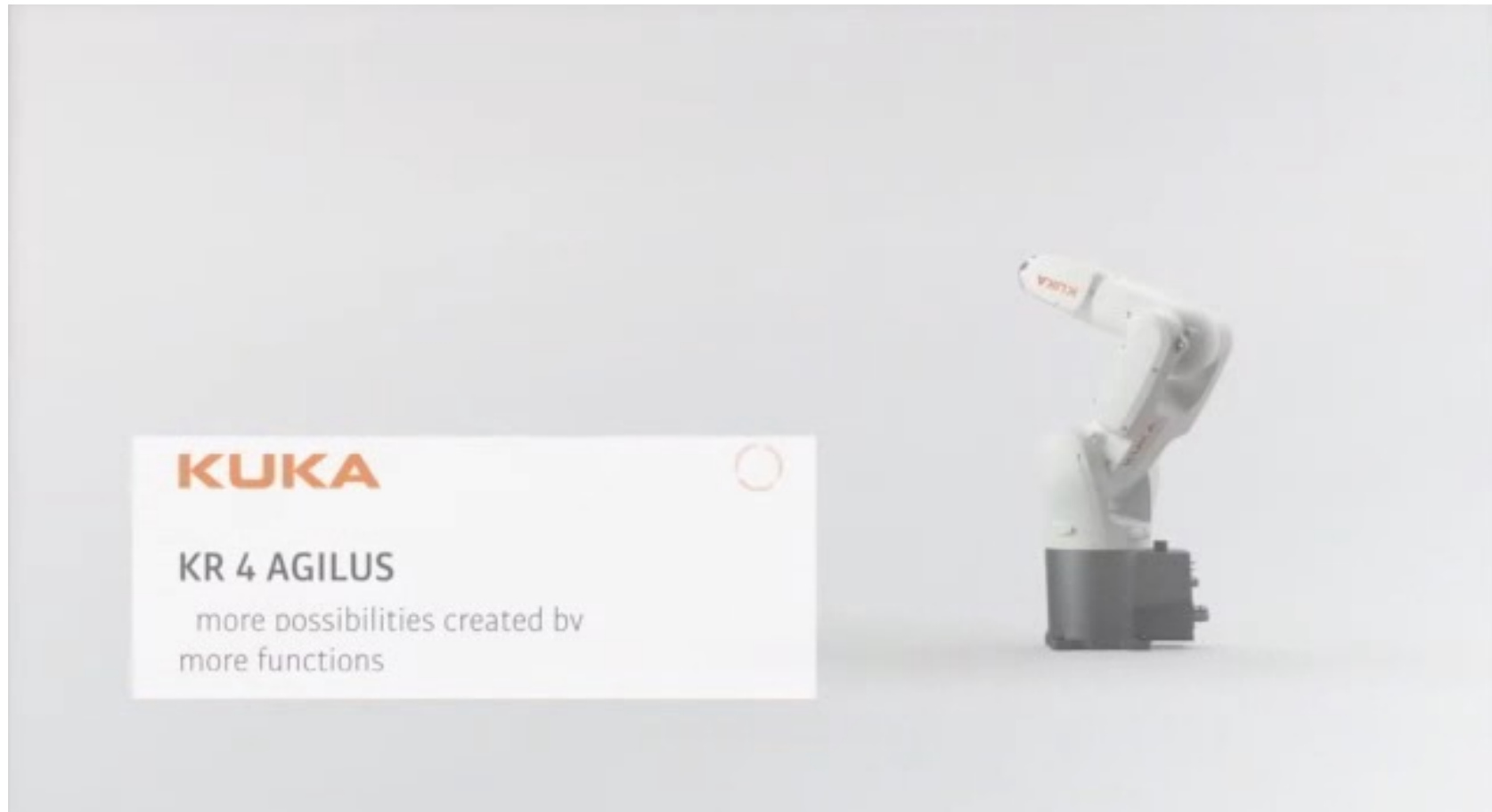
- robot “anatomy”
- provide tools for kinematic analysis of articulated chains of multiple rigid bodies (= robot manipulators)
- analytical methods for planning motion trajectories
- motion commands and control algorithms
- programming of tasks for industrial & service manipulators



A robot manipulator

Illustrating typical features of an industrial robot

commercial video



KUKA KR 4 Agilus robot with 6 revolute joints

Robot in action

Universal Robots UR-10



commercial
video

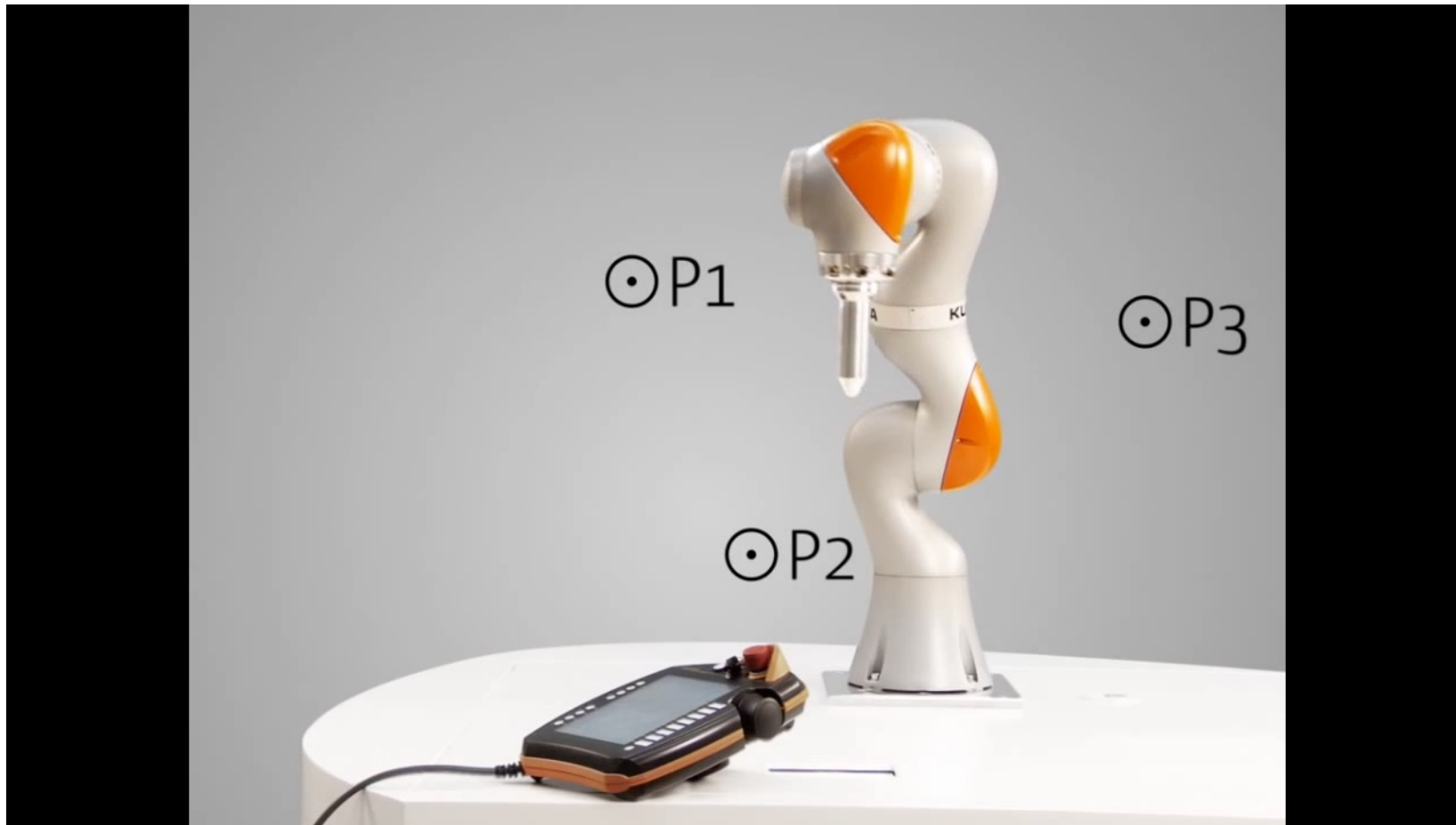
1. Pick-and-place on factory floor
2. CNC Machine loading
3. Palletizing egg-boxes
4. Automation in biomedical lab
5. Surface polishing (with prescribed contact force)
6. Quality control
7. Assembly
8. Robot in a cell
9. Base mounting from the top
10. Pick-and-place on conveyor belt



Programming robot motion

Teaching Cartesian poses and playing them back

video



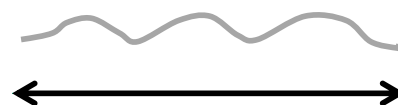
KUKA LBR iiwa robot with 7 revolute joints



Programming robot motion

Executing nominal trajectories and “complying” with uncertainties

video

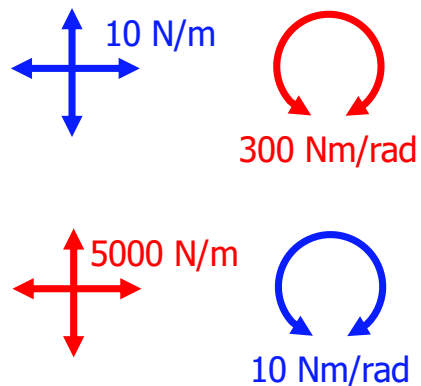
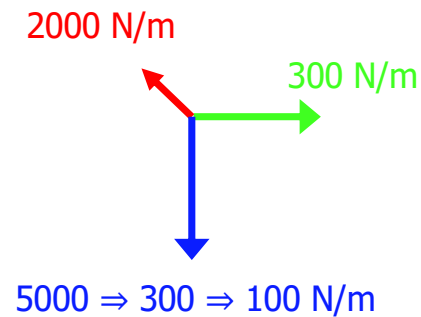


actual
nominal

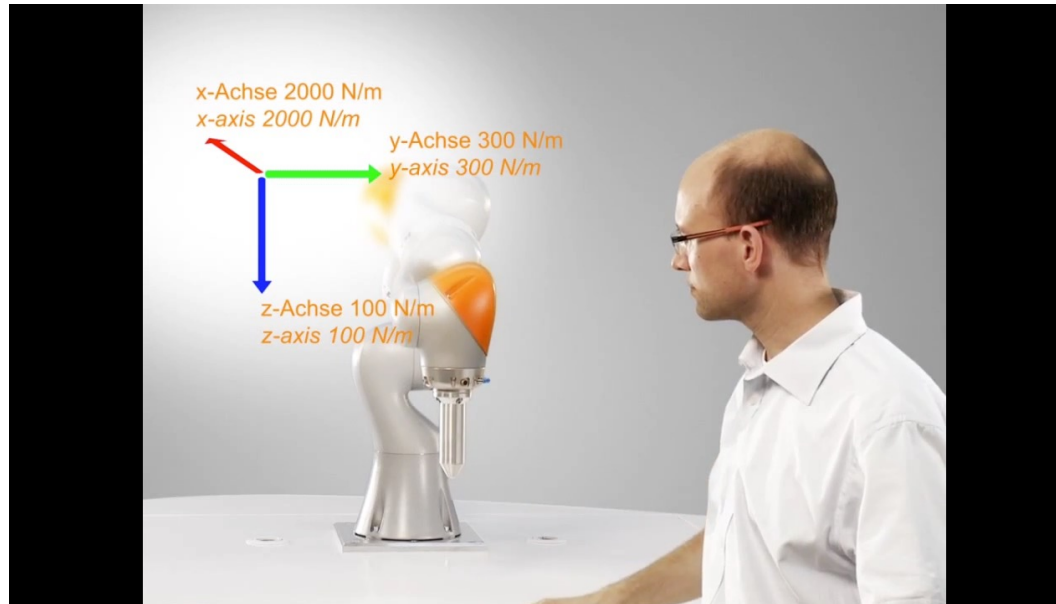
↑
↓
compliance

Programming robot compliance

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



Robotics 1



video

units
[N/m]

$\Delta p \rightarrow F = K \Delta p$

stiffness

VS

compliance

$$F \rightarrow \Delta p = C F$$

$$= \frac{1}{K} F$$

video



Industrial vs. service robots

FANUC

FANUC's New
CR-35iA
Collaborative Robot
Hand Guidance
Feature



FANUC CR35i 6R collaborative robot
carrying up to 35 kg of payload,
with hand guidance system

video

video

qbrobotics SoftHand2
dexterous robot hand
with only 2 motors on board
and compliant transmissions
(based on human hand **synergies**)



Robot manipulators at DIAG Robotics Lab (S-218)



3 videos



KUKA KR-5
(small size, industrial)

Robotics 1



KUKA LWR4+
(lightweight, about 14 kg)



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

12

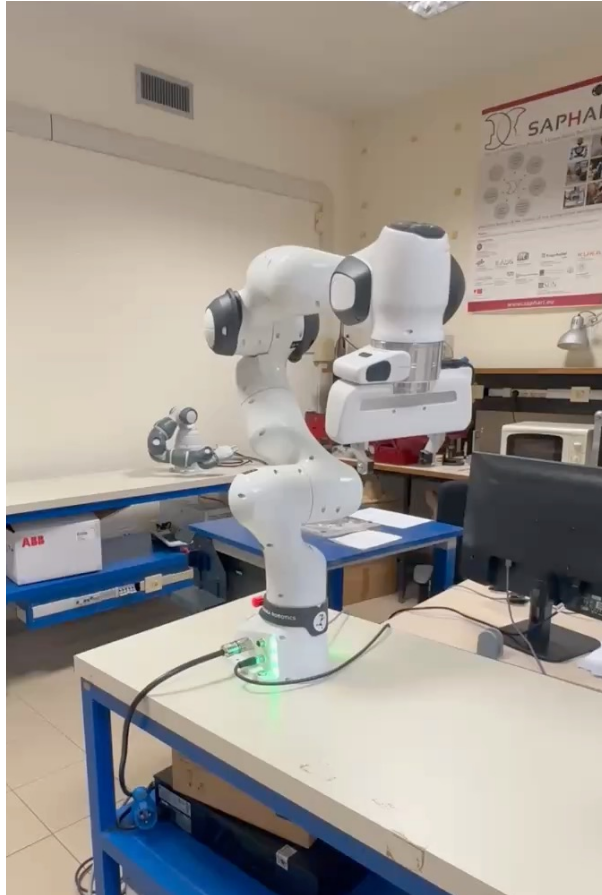


New collaborative robots at DIAG Robotics Lab (S-218)

video

motion and
interaction
programs in
C++/Python

equipped with
joint torque
sensors



7R Franka Emika R3

video

motion and
interaction
programs in
ABB Rapid or
C++/Python



(two) 7R ABB YuMi

DIAG Robotics Lab YouTube channel for more of our research videos

www.youtube.com/user/RoboticsLabSapienza



Program

■ Introduction

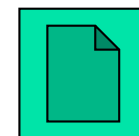
- Manipulator arms (+ some on a mobile base)
- Industrial and service applications

■ Components

- Mechanical structures
- Actuators and transmissions
- Sensors
 - proprioceptive (encoders, velocity reconstruction, ...)
 - exteroceptive (force/torque, depth, vision, infrared, ultrasound, laser)

■ Kinematic models

- Representations of orientation (rotation matrices, Euler angles, ...)
- 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

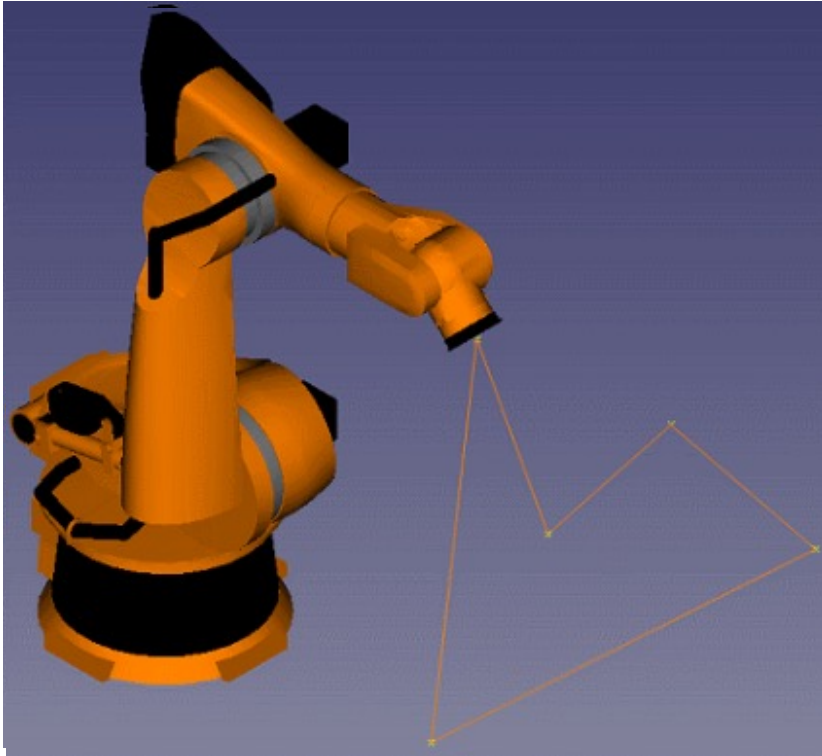




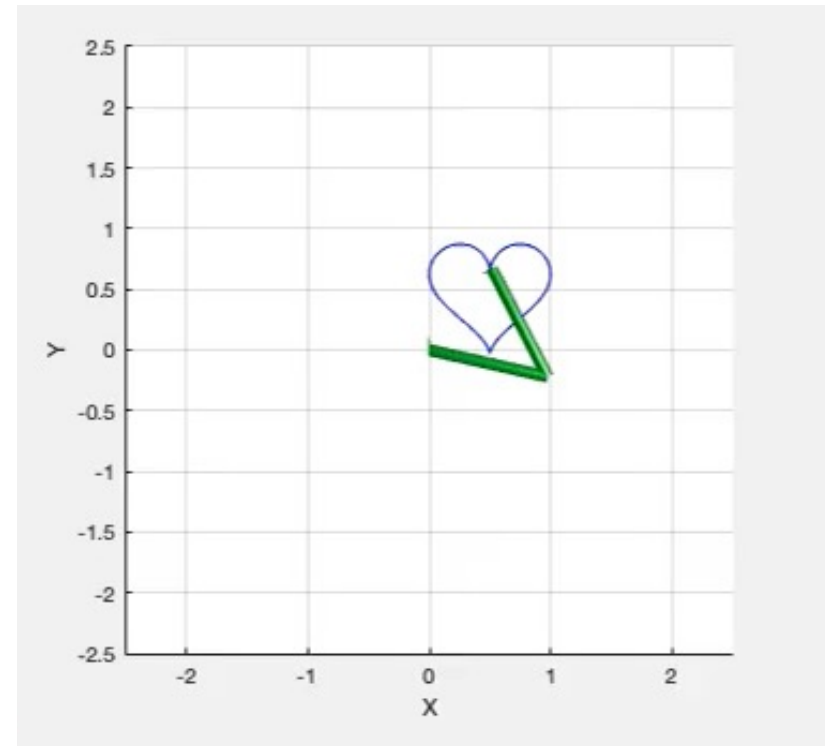
Program (continued)

- **Planning of motion trajectories**
 - Trajectory: a geometric path with a timing law
 - Planning in joint space for robot manipulators
 - Planning in 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, Rapid)
 - Use of Matlab/Simulink (with Robotics Toolbox) or CoppeliaSim (V-REP)

Planning Cartesian trajectories



KUKA 6R articulated robot



video



2R planar robot

timing
law
geometric
path

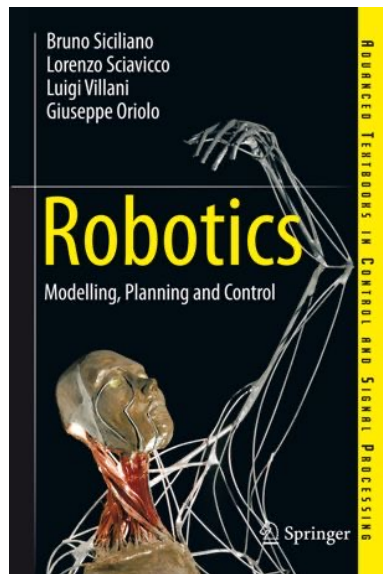
```
t = [0:Ts:T]; tau = t/T; s = (-2*tau.^3 + 3*tau.^2); center = [0.5; 0.5];
p = center + [(16*sin(2*pi*s).^3)/16;
(13*cos(2*pi*s) - 5*cos(4*pi*s) - 2*cos(6*pi*s) - cos(8*pi*s))/16]/2;
```

MATLAB code (Diacò & Ficirolli, Sep 2021)

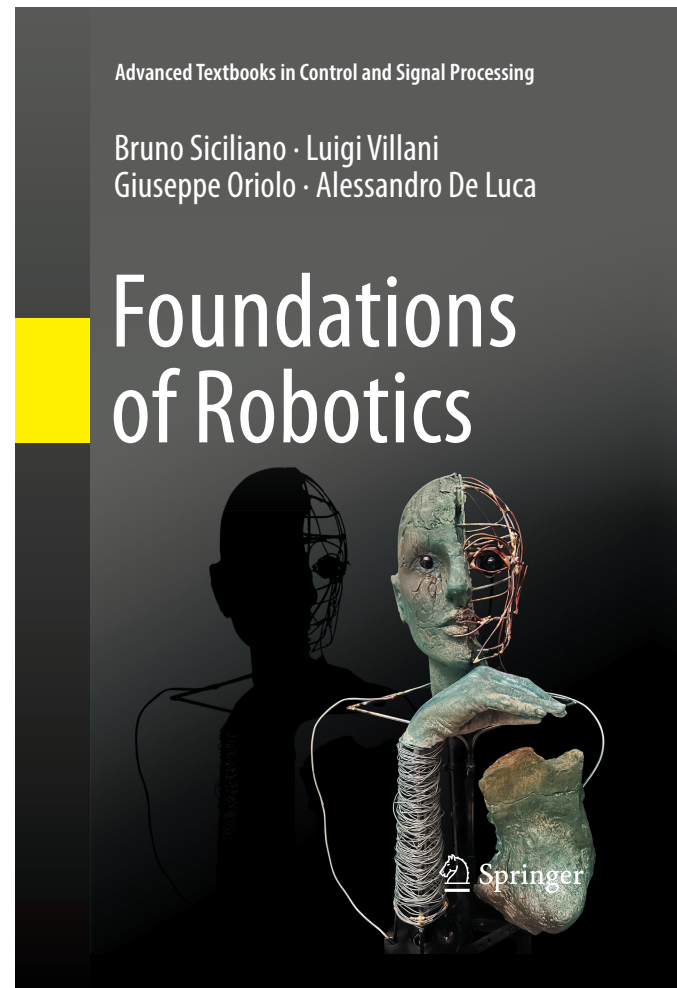


A new textbook!

B. Siciliano, L. Villani, G. Oriolo, A. De Luca: **Foundations of Robotics**, Springer, 2025: <https://link.springer.com/book/10.1007/978-3-031-85523-8>



worldwide best seller since 2009
(with Italian, Chinese, Greek editions)



published on
September 6,
2025
(eBook,
Hardcover,
Softcover)

12 chapters
5 appendices
190+ problems
719 pages



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some topics will be skipped
(new syllabus in preparation
on course webpage!)

find typos or mistakes
and earn points for the exam!



Other course materials

- **Course website** www.diag.uniroma1.it/deluca/rob1_en.php
 - pdf of lecture slides **ready** (with some **updates** during the course)
 - all videos shown during lectures (in zipped folders by block of slides)
 - written exams (most with solutions), syllabuses, extra documents, ...
- **Video DIAG channel** playlist [Robotics 1](#) with full course of **2014-15**
 - 30 (+1 index) videos in classroom (\cong **41h**, **>157K** independent views)
- **YouTube** [personal channel](#): playlists with videos of **selected** lectures recorded during the pandemic (2019-20 and 2020-21)



Exams and beyond

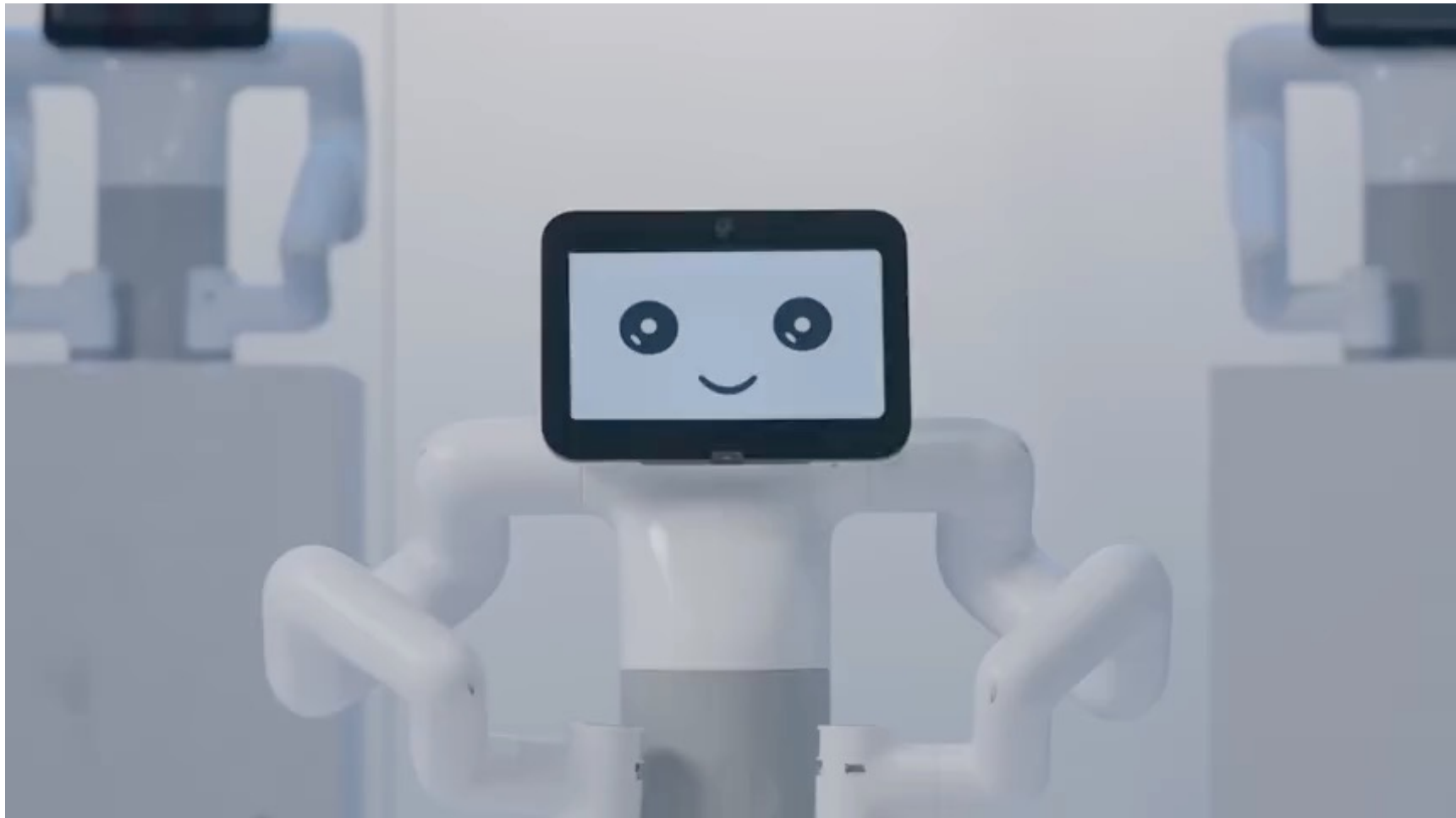
- Type: **midterm** test (mid November) + **written** exam (**open books**)
- Schedule 2025-26
 - 2 sessions at the end of this semester
 - between January 7 and February 20, 2026
 - 2 sessions at the end of next semester
 - between June 3 and July 30, 2026
 - 1 session after the summer break
 - between August 31 and September 22, 2026
 - *2 extra sessions **only** for students of previous years, part-time, ...*
 - *March 16–April 30 and October 7–November 5, 2026*
- Signing up to exams
 - on infostud (up to **one week before** the date of the written exam)
- Master theses
 - samples at DIAG Robotics Lab www.diag.uniroma1.it/labrob/theses

will open
on infostud
in early December
check the
course website!

Programming motion and behavior



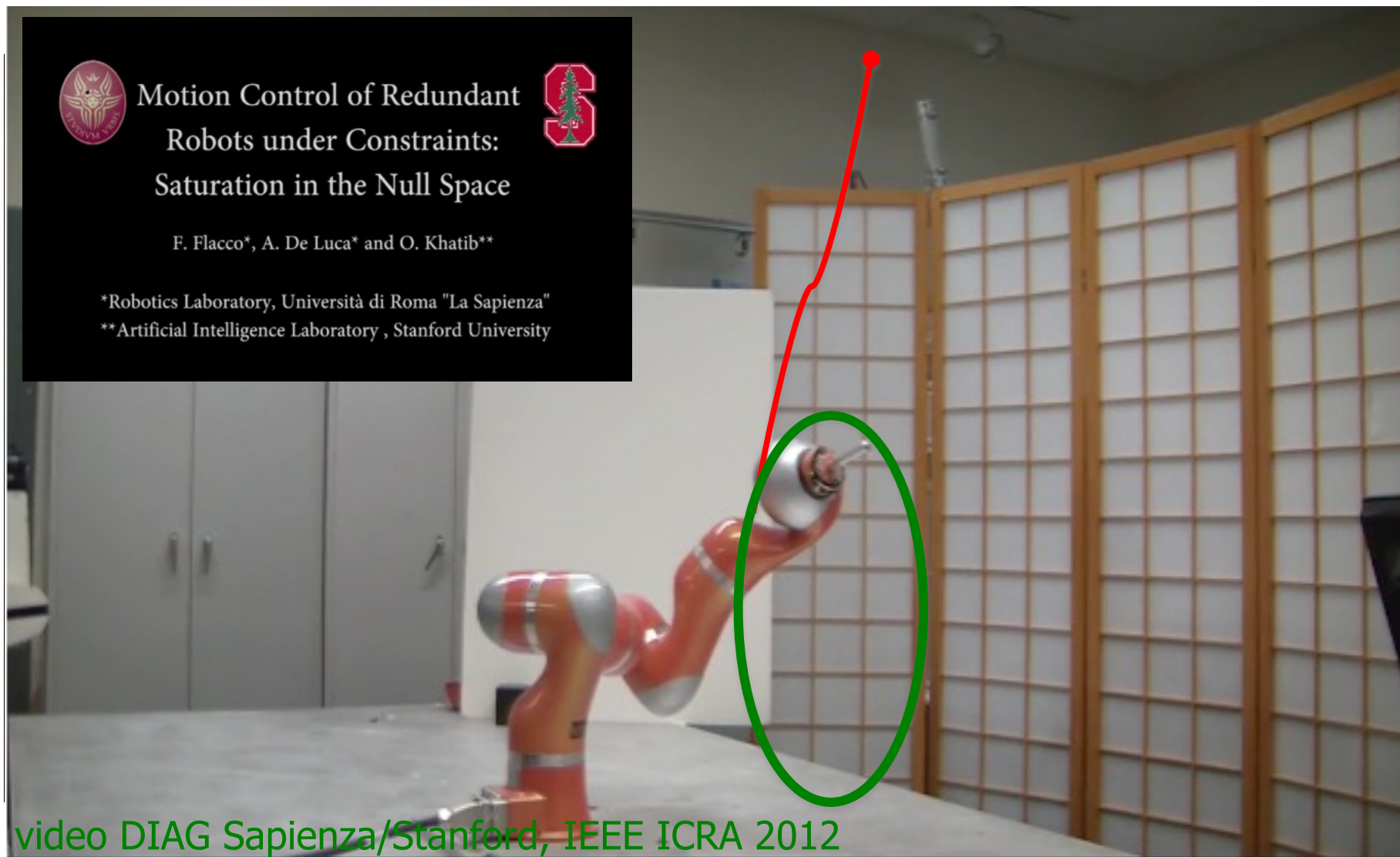
video



myBuddy 280-Pi dual-arm personal robot by Elephant Robotics



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



Robot control by visual servoing

with limited joint motion range



Avoiding joint limits with a low-level fusion scheme

Olivier Kermorgant and François Chaumette

Lagadic team
INRIA Rennes-Bretagne Atlantique

video INRIA Rennes, IEEE/RSJ IROS 2011

Sensor-based robot control

in dynamic environments (coexistence with human)



A Depth Space Approach to Human-Robot Collision Avoidance

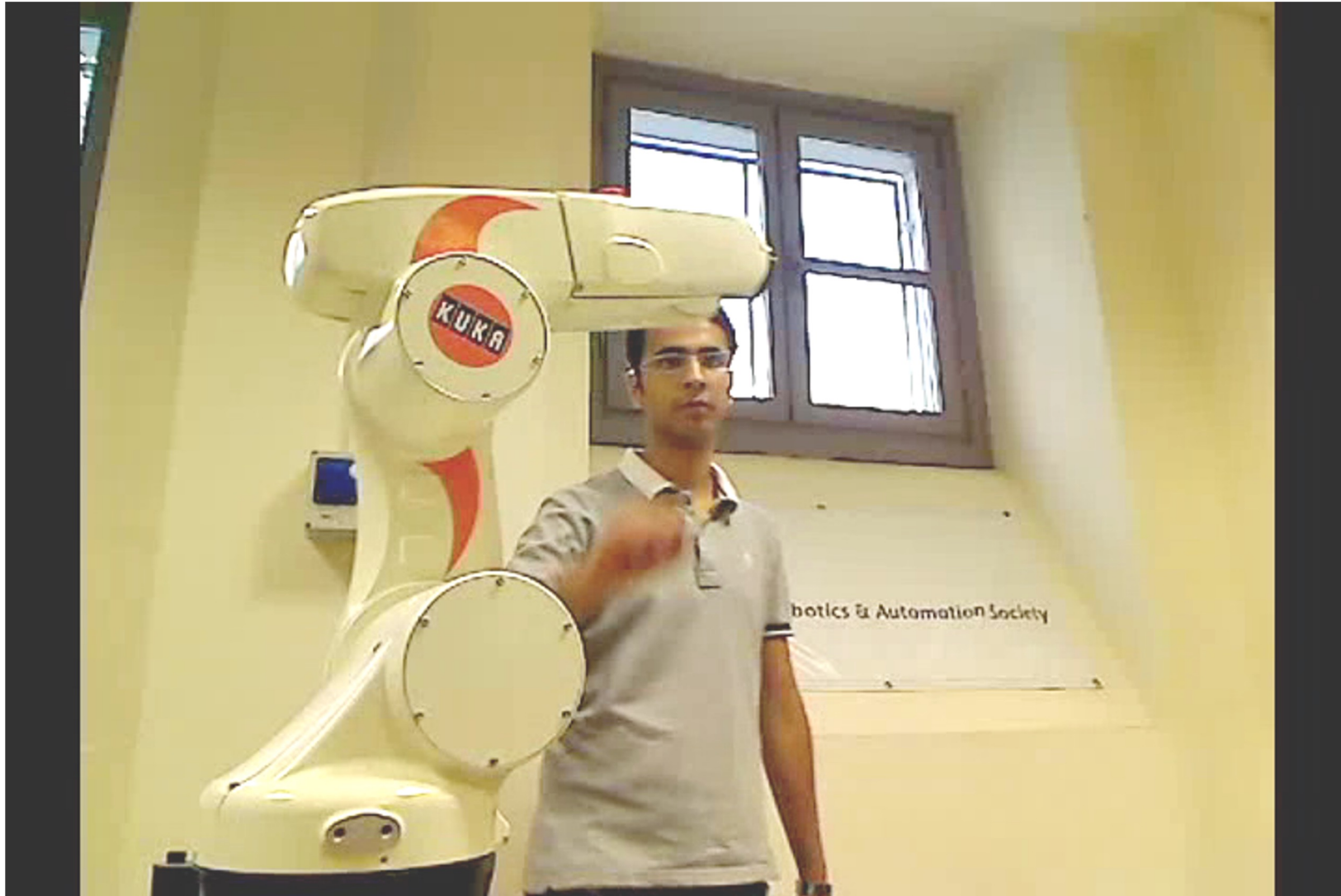
F. Flacco*, T. Kröger**, A. De Luca* and O. Khatib**

*Robotics Laboratory, Università di Roma "La Sapienza"

**Artificial Intelligence Laboratory, Stanford University

video DIAG Sapienza/Stanford, IEEE ICRA 2012

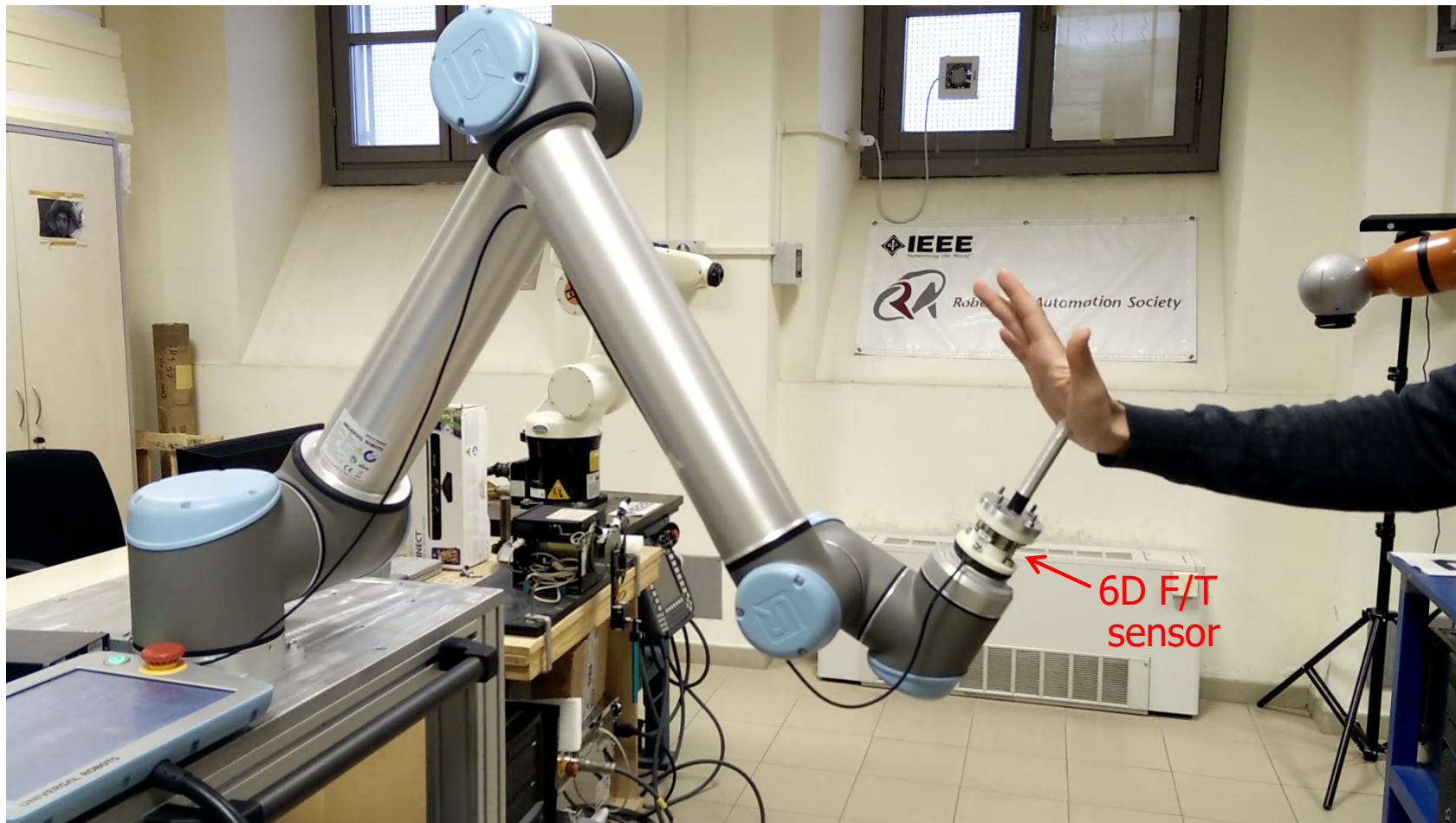
Safe physical human-robot interaction (sensor-less (!) and on a conventional industrial robot)



video DIAG Sapienza, IEEE ICRA 2013

Human-robot collaboration

(with a real F/T and “virtual” sensors to distinguish contacts)

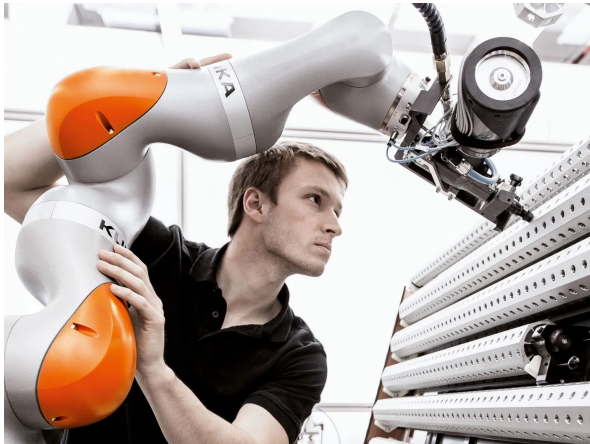


video DIAG Sapienza, J. of Mechatronics, 2018

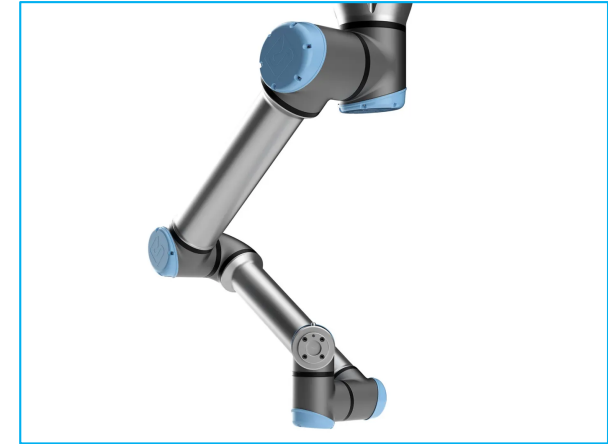


More robots ...

@IEEE <https://robotsguide.com>



KUKA LBR iiwa
7-dof arm
DE 2013



UNIVERSAL ROBOTS
UR5 6-dof arm
DK 2008

<https://youtu.be/7GdiN6KmGCc>

<https://youtu.be/UQj-1yZFEZI>



ABB YuMi-FRIDA
bi-manual arm
SE-CH 2011



OCRobotics Explorer
snake arm
UK 2009

<https://youtu.be/70V6J4Y8hnc>

https://youtu.be/_gU6TWGynkU

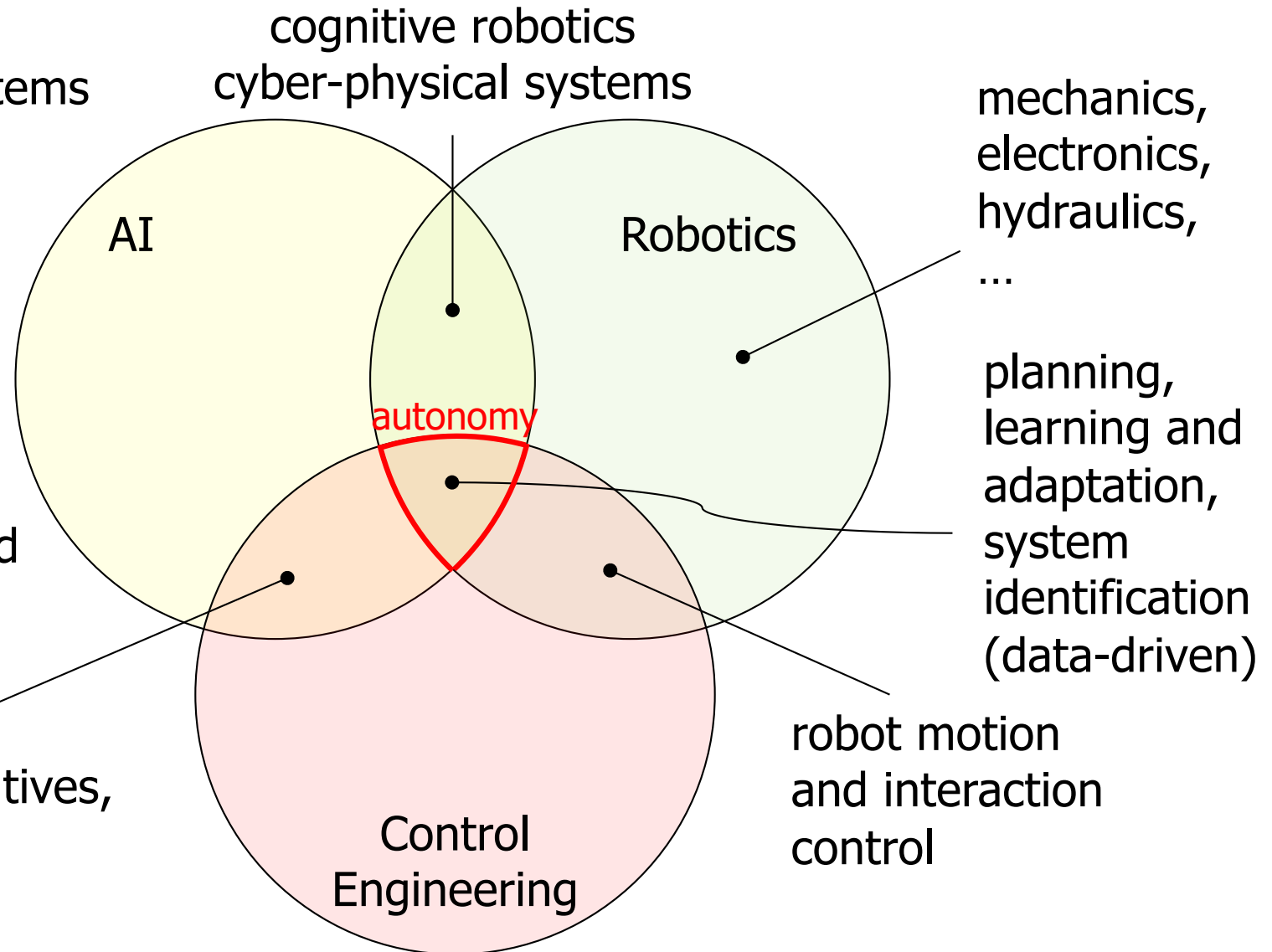
Next generation of intelligent robots?



Robots =
embodied AI systems

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

model-based
techniques,
dynamic primitives,
uncertainty



AI and Robotics

manipulation tasks



Toyota Research Institute
(work by Russ Tedrake)

dishwasher loading:
a manipulation task (speeded up!)
that integrates planning, vision,
learning and control

[video](#)

[video](#)

pick-and-place motion:
programming a manipulation task
from LLM commands
(using a library of motion primitives!)

Microsoft
ChatGPT for Robotics

ChatGPT - Robot Manipulation

AI and Robotics

foundation models



π_0 by Physical Intelligence (Nov 2024) or RT-X by Google DeepMind (Oct 2023)

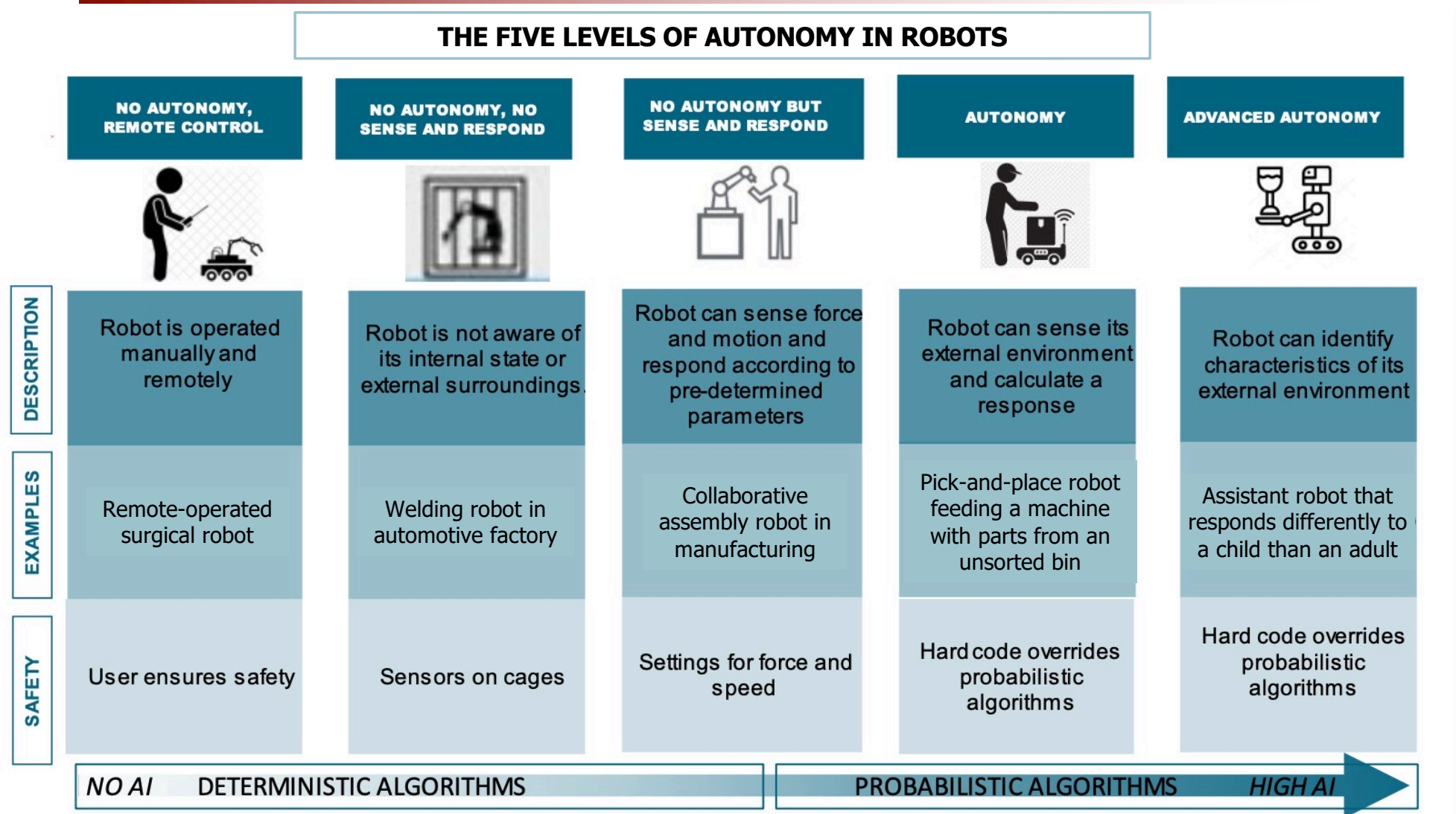
- model trained on broad and diverse data (including text instructions)
- embodied robot experience: learning directly low-level motor commands
- generalization over tasks and robots



video



Levels of robot autonomy in industrial applications



source, IFR 2022



Horizon Europe (2021-27)



[local link to the document](#)

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



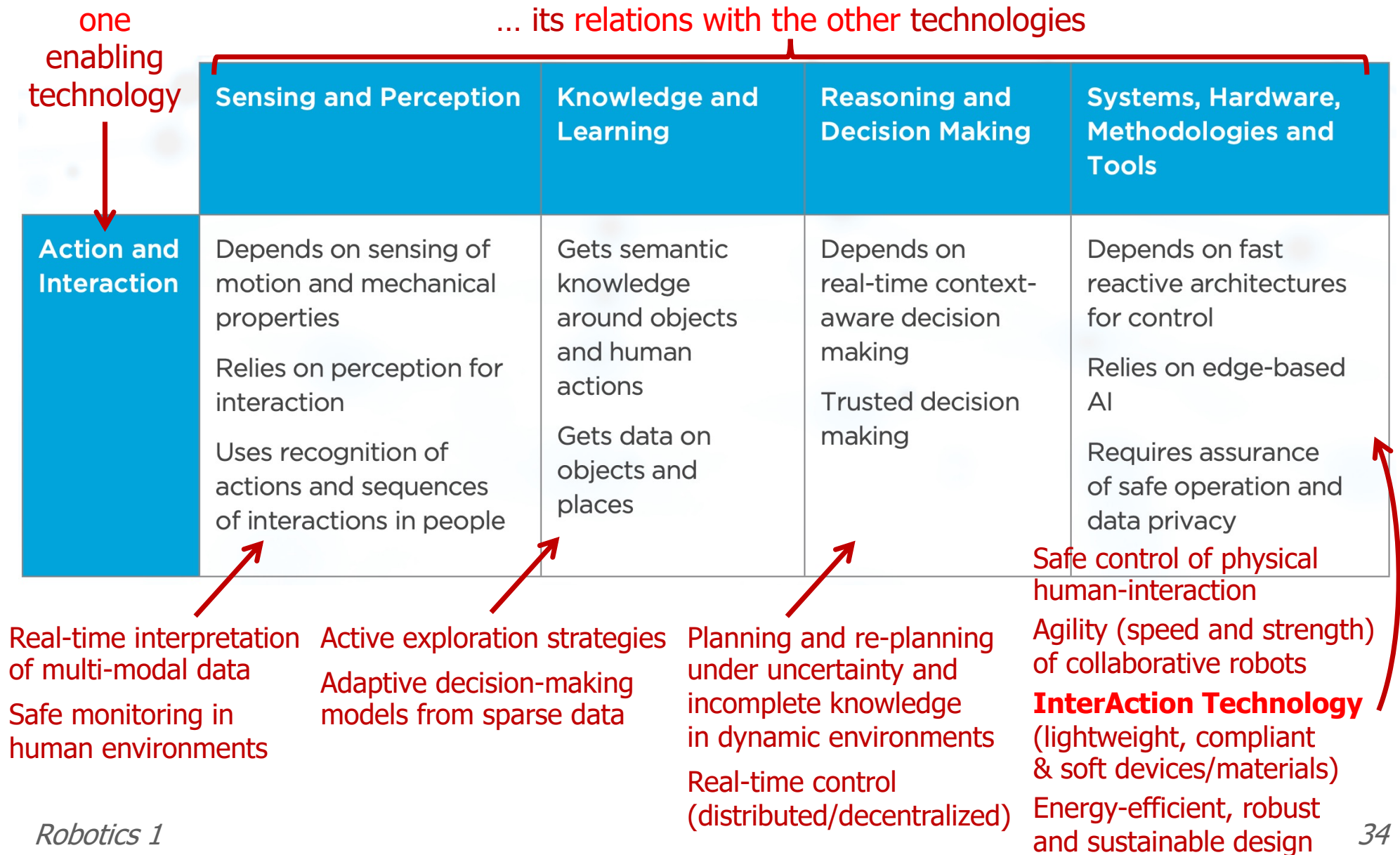
Specific to Robotics

- hard physical/real-world nature of Robotics (“AI embodied”)
- wide range of technologies are integrated within robotic systems
- skill mix needed for success is broader than in AI or Data alone
- robots are realizations of advanced system-level concepts
 - such as autonomy, control, sensing, perception 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, Covid19, Humanoids at home



AI & Robotics point of views

example with one of the cross-sectorial technology enablers





Robotics around the world...

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

robots
the journey continues

Preview of Robotics 2

6 credits, II semester, year 1



- **Advanced kinematics / Robot dynamics**
 - Calibration
 - Redundant robots
 - Dynamic modeling: Lagrange and (recursive) Newton-Euler methods
 - Identification of dynamic parameters/coefficients
 - Geometrically constrained dynamics
- **Control techniques**
 - **Free motion** linear/nonlinear feedback control, robust control, adaptive control, iterative and online learning
 - **Constrained motion** admittance, impedance, hybrid force-motion control
 - **Visual servoing** (kinematic approach)
- **Special topic**
 - Diagnosis and isolation of robot actuator faults



Textbook contents for Robotics 2

B. Siciliano, L. Villani, G. Oriolo, A. De Luca: **Foundations of Robotics**, Springer, 2025

<https://link.springer.com/book/10.1007/978-3-031-85523-8>

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more topics are also part of the program
(new syllabus in preparation
on course webpage!)



Other courses on 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/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, students take 2 modules out of the 4 in EiR)
 - research-related subjects: e.g., **physical robot interaction** (with humans, aerial, ...)
 - multiple instructors www.diag.uniroma1.it/vendittelli/EIR
- **Probabilistic Robotics (6 credits), I semester, year 2**
 - Least Squares state estimation, Kalman filter, SLAM
 - Prof. Grisetti sites.google.com/diag.uniroma1.it/probabilistic-robotics-2025-26
- **Robot Programming (3 credits, no mark), I semester, year 1**
 - robot programming using C++, modules with ROS, embedded real-time coding
 - Prof. Grisetti sites.google.com/diag.uniroma1.it/robot-programming-2025-26

I-RIM conference 2025

Gazometro Roma, 17-19 October 2025



- Institute of Robotics and Intelligent Machines (I-RIM)
 - national association of academic and industrial stakeholders
 - created in 2019
 - check the web site for multiple initiatives: <https://i-rim.it/en>
- 7th national I-RIM conference
 - scientific presentations, workshops, expo, demos ...
 - in conjunction with [MakerFaire Europe](#)
 - registration for students is very low
- Student staff is needed!! Contact asap: a.demofonti@unicampus.it

