Underactuated Robots

Profs. Leonardo Lanari and Giuseppe Oriolo

Introduction to the course

Dipartimento di Ingegneria Informatica Automatica e Gestionale Antonio Ruberti

Sapienza Università di Roma

motivation

current robots move far too conservatively (slow, clumsy, overly cautious) with respect to their actual mechanical capabilities

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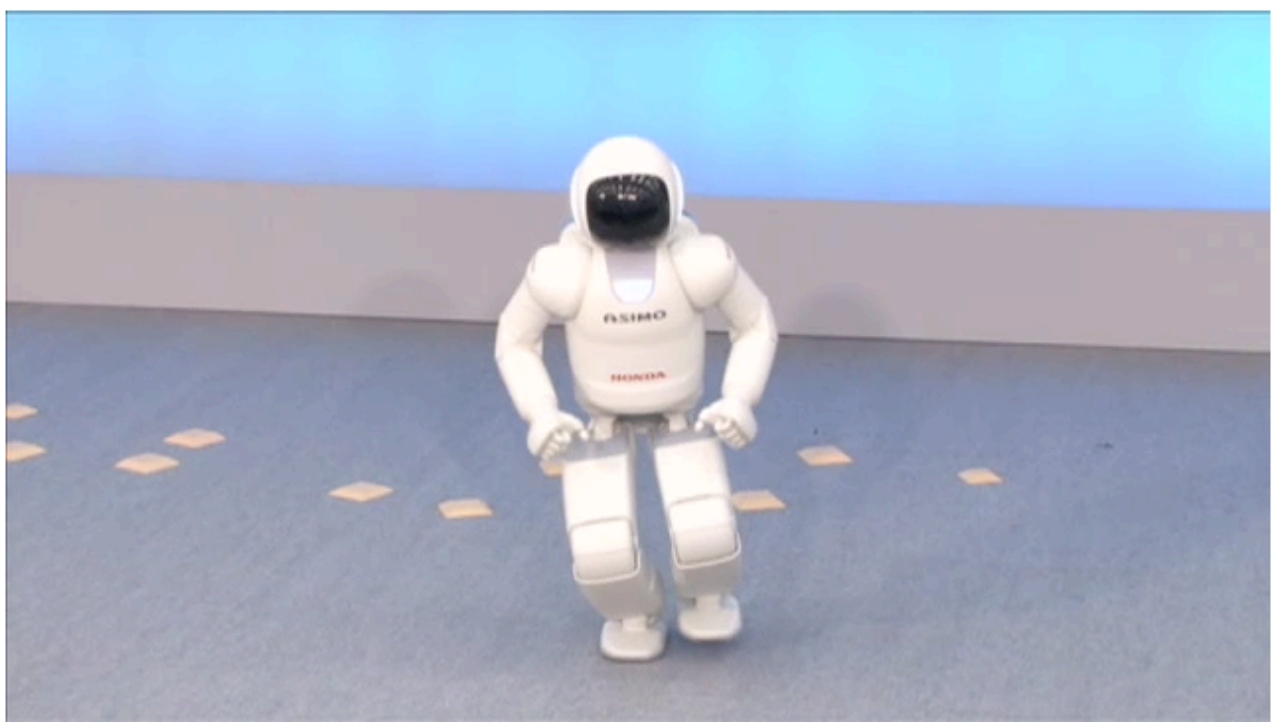


motivation

- most robot control techniques are based on the idea of using feedback to override the dynamics of the mechanism
- to achieve fast, efficient, agile motions we need planning and control methods that exploit the natural dynamics (e.g., inertial couplings, gravity, elasticity etc) of the system rather than canceling it
- underactuated systems (i.e., systems with less actuators than degrees of freedom) are the archetypal class of mechanism which can be controlled only with this approach

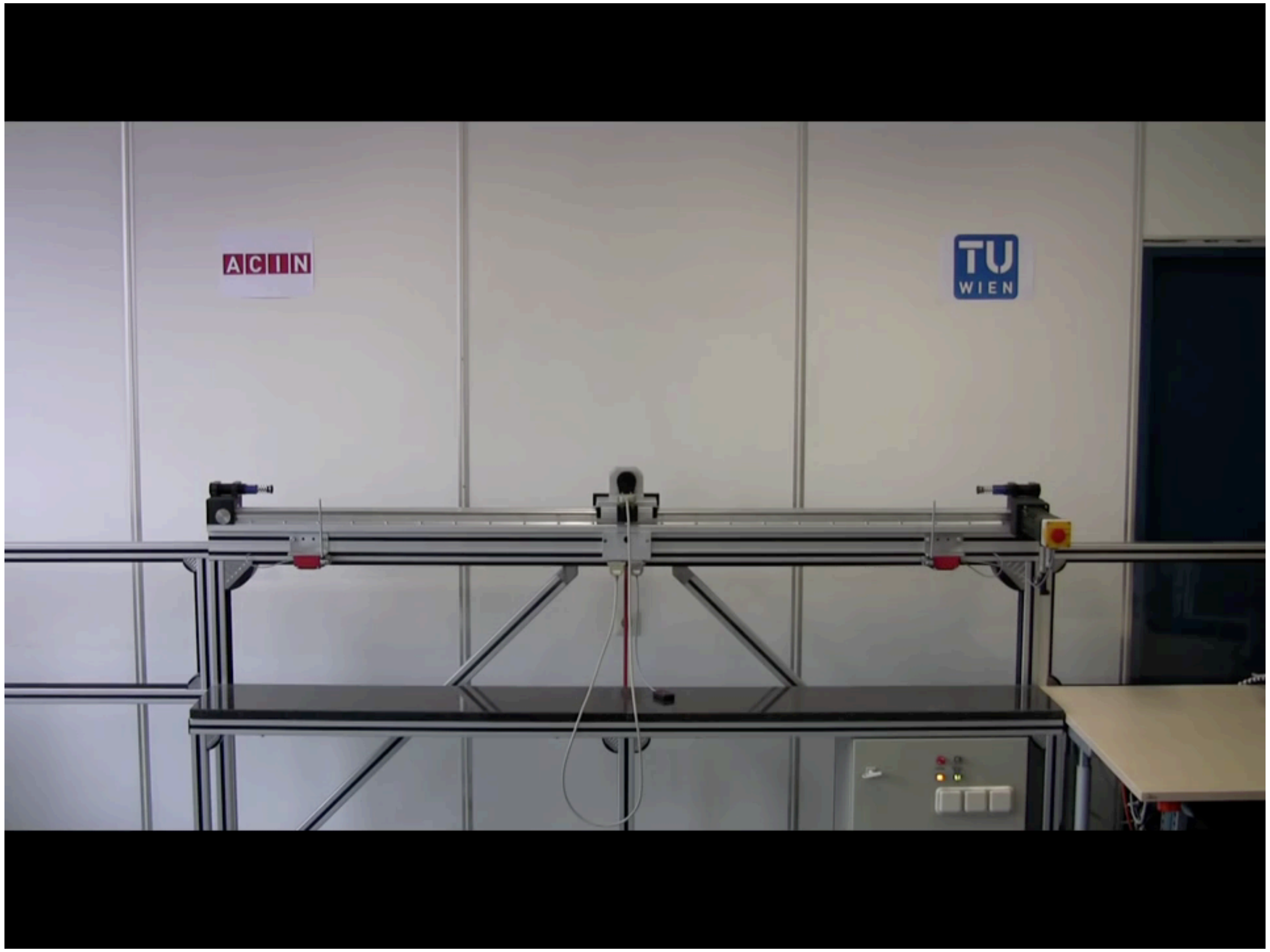
motivation

- sometimes underactuation is intrinsic to the nature or the prevailing design of the mechanism
- sometimes it is an intentional choice aimed at reducing size, weight, cost, energy consumption, provided that the robot can still be controlled to perform the desired task (minimalistic approach)

examples of underactuation

- gymnast robots
- legged robots
- flying robots
- snake robots
- multifingered hands
- manipulation systems
- …

gallery



the cart-pendulum

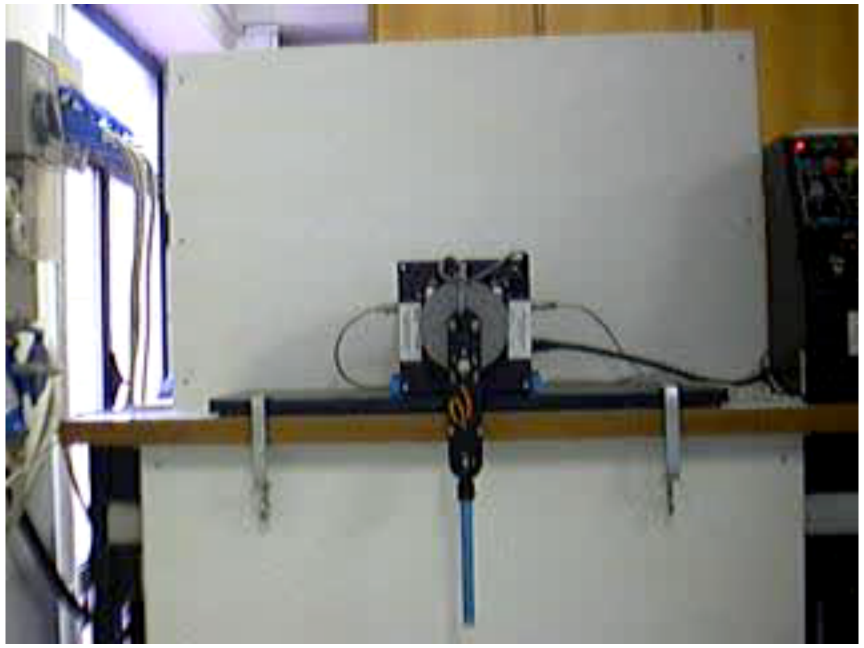
gallery

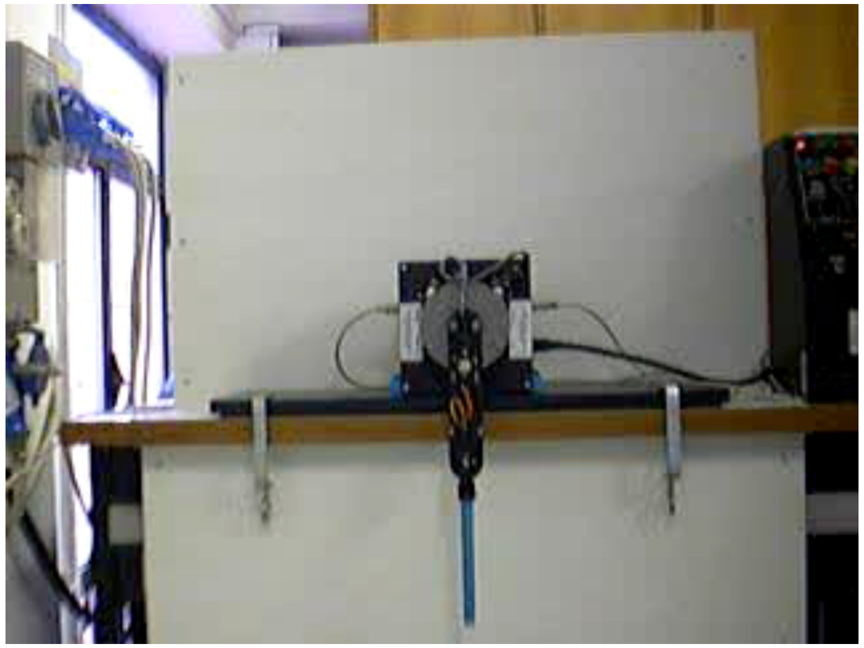
the Acrobot

gallery

a brachiating robot

gallery





the Pendubot

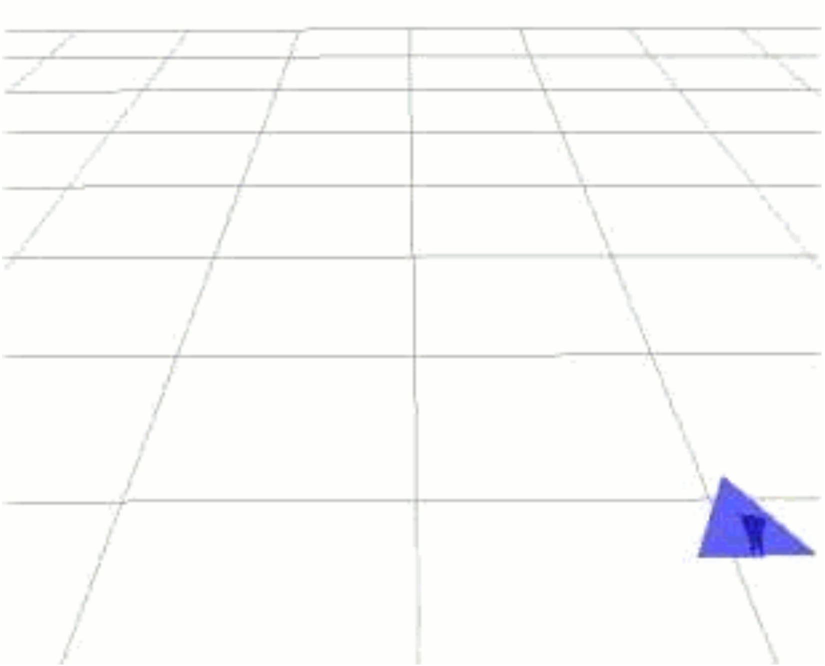
gallery

passive walkers

gallery

quadrotors

gallery

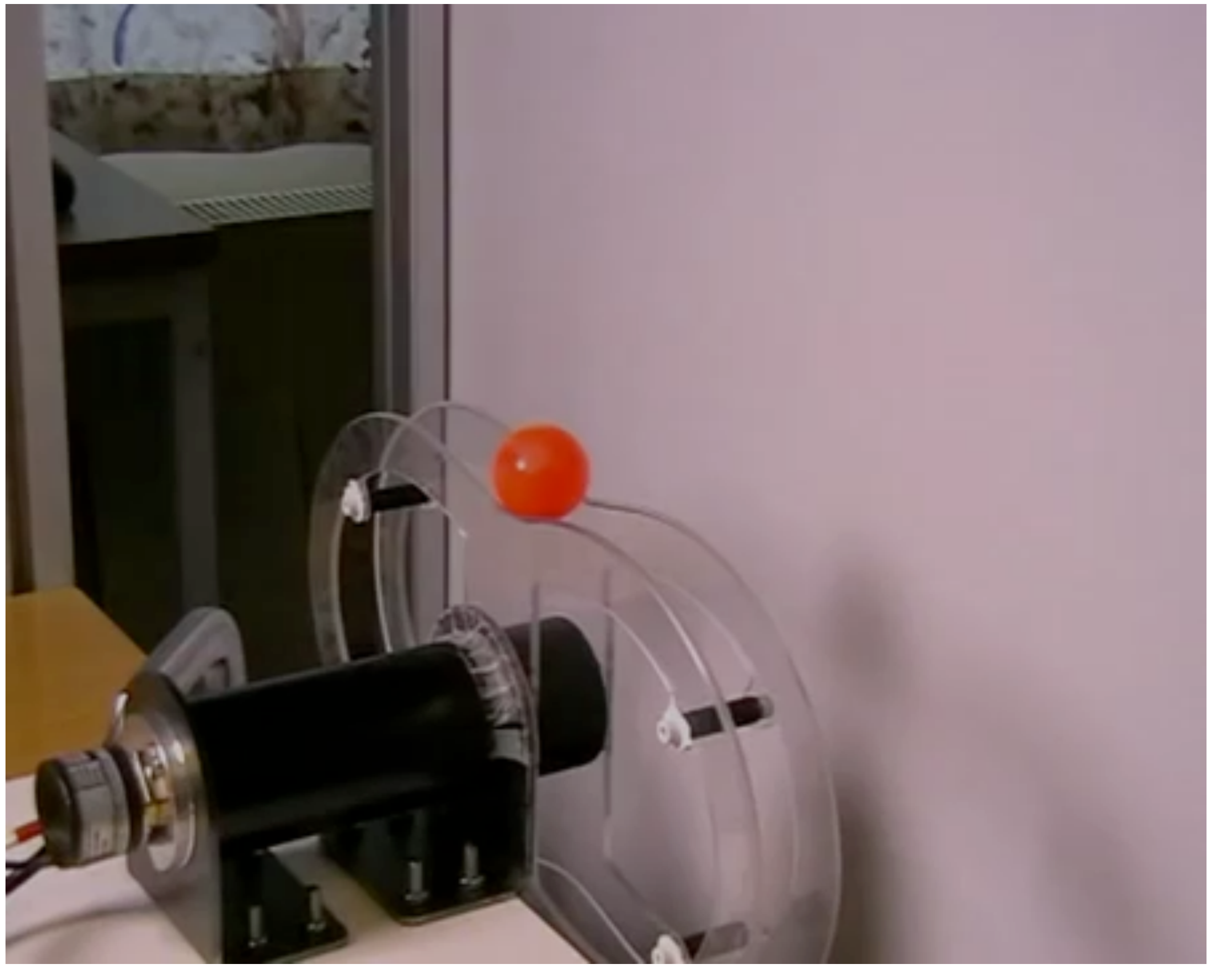


a barrel roll

gallery

synergies in robotic hands

gallery



the Butterfly

gallery

a snake robot

syllabus/1

1. **Introduction**

Motivation. Definition of underactuated system (generalized coordinates vs degrees of freedom). Examples of underactuated robots.

2. **Modeling and Properties**

Eulero-Lagrange modeling (classic and alternate). State-space form. Control problems of interest. Controllabiity (STLA, STLC, natural controllability). Comparison with fully actuated robots. Integrability conditions for passive dynamics. Equilibrium points and linear controllability.

3. **Case Studies: Acrobot and Pendubot**

Modeling. Approximate linearization at equilibria. Linear controllability. Balancing. Partial feedback linearization. Swing-up (1) via analysis of the zero dynamics (2) via energy pumping.

4. **Zero dynamics in underactuated systems**

Normal form and zero dynamics. Importance of the zero dynamics in control. Zero-dynamics in linear and nonlinear underactuated systems. The homoclinic orbit.

syllabus/2

5. **Passivity**
Definition and physical interpretation. Linear and nonlinear mechanical systems examples. Dissipativity in state space representations. Feedback equivalence to a passive system. Output stabilization of passive systems

6. **Energy-based control of underactuated systems**
The convey-crane and reaction-wheel cases.

7. **Optimization methods for planning and Control**
Introduction to Dynamic Programming. Hamilton-Jacobi-Bellman equation. Derivation of the Linear Quadratic Regulator. Linear-Time-Varying LQR. Trajectory optimization with Iterative LQR. Constrained optimization. Model Predictive Control (Linear, LTV and Nonlinear). LQR-trees.