Pierluigi Arpenti

Tutor: Vincenzo Lippiello

XXXIII Cycle - I year presentation

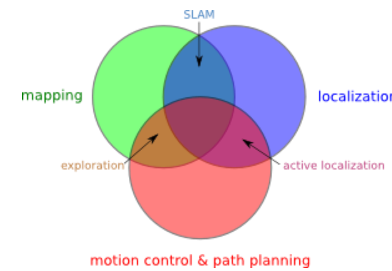
Passivity-Based Approaches to Locomotion Control of Walking Bipedal Robots

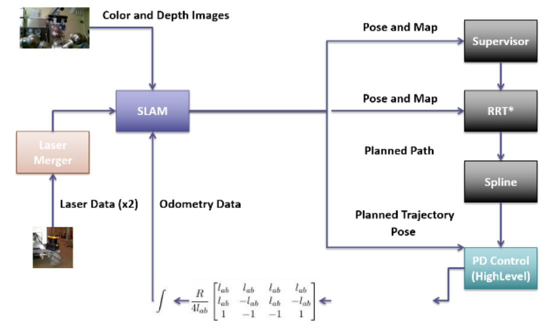
Università degli Studi di Napoli Federico II

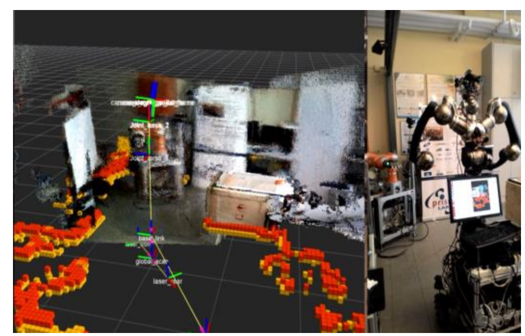
Background

M.Sc. in Automation Engineering – Università degli Studi di Napoli Federico II, Department of Information Technologies and Electrical Engineering – September 2016

— Master thesis title:
"A High Level Control Architecture for Simultaneous Localization, 3D Mapping and Navigation for Mobile Robots",
developed at Prisma Lab
of Università degli Studi di Napoli Federico II







— Currently PhD student in
Information Technology and
Electrical Engineering, XXXIII Cycle,
at Università degli Studi di Napoli Federico II
with a MIUR fellowship, supervised by
Prof. Vincenzo Lippiello and Dr. Fabio Ruggiero

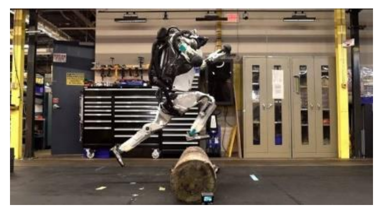
Research Problem

Underactuated Robotics

Underactuated robots exhibit a lower number of actuators than degrees of freedom

- Walking-Robots
- Flying-Robots
- Robot-Manipulators
- …



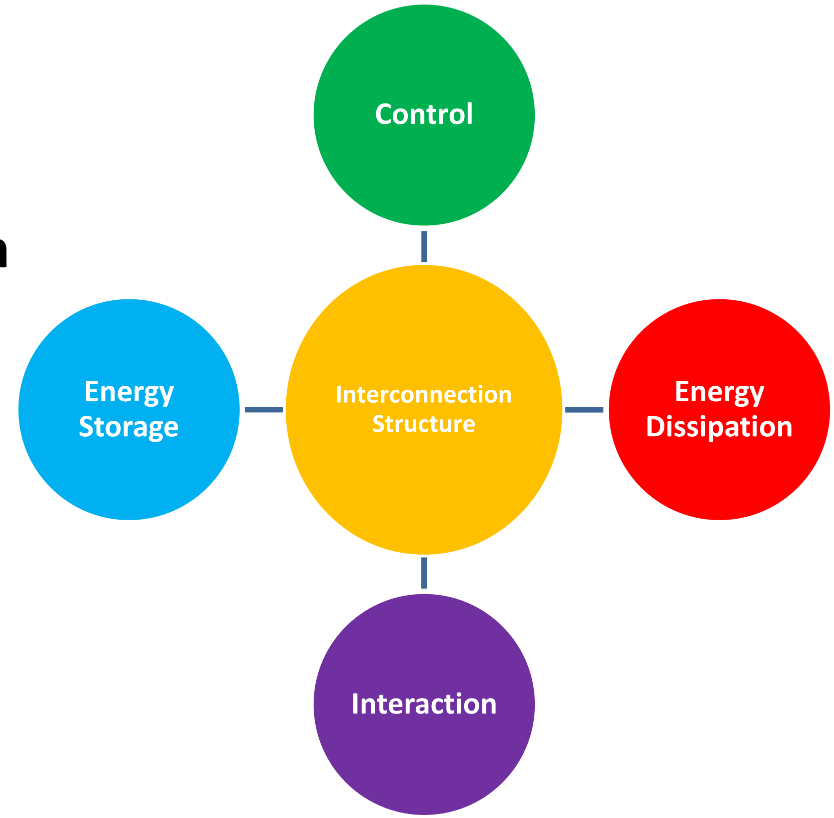



To achieve outstanding dynamic performances (efficiency, agility, and robustness) ,design control systems which take advantage of the non-linear dynamics, not cancel them out

Research Activity

Adopted Methodology: the p-H framework

The port-Hamiltonian framework expresses the dynamic of a system in terms of generalized coordinates and momenta modeling the system from an energetic point of view



$$\underbrace{\begin{bmatrix}\dot q\\ \dot p\end{bmatrix}}_{\dot x} = \left\{\underbrace{\begin{bmatrix}0 & I\\ -I & 0\end{bmatrix}}_{J} - \underbrace{\begin{bmatrix}0 & 0\\ 0 & D\end{bmatrix}}_{R}\right\}\underbrace{\begin{bmatrix}\frac{\partial H(q,p)}{\partial q}\\ \frac{\partial H(q,p)}{\partial p}\end{bmatrix}}_{\frac{\partial H}{\partial x}} + \underbrace{\begin{bmatrix}0\\ I\end{bmatrix}}_{g}\underbrace{F}_{u}$$

Research Activity

Adopted Methodology: the IDA-PBC

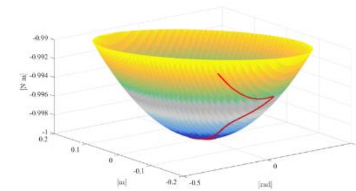
Interconnection and Damping Assignment Passivity-Based Control

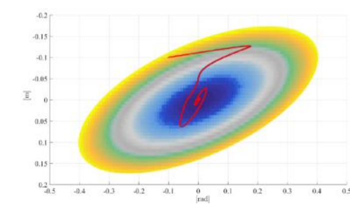
Pro

— Exploit the non-linear dynamics of the system

— Physical interpretation of the control law
(Lyapunov function is the **Hamiltonian** of the system)

— Energy efficient





Cons

— Solving a set of non-linear partial differential equations which arise matching the open loop dynamics with the desired closed loop ones

Open loop PHS

$$\dot{x} = \Big[J(x) - R(x)\Big]\frac{\partial H}{\partial x} + g(x)u$$

Closed-loop PHS

$$\dot{x} = \Big[J_d(x) - R_d(x)\Big]\frac{\partial H_d}{\partial x}$$

Matching open and closed-loop PHS

$$\Big[J(x) - R(x)\Big]\frac{\partial H}{\partial x} + g(x)u = \Big[J_d(x) - R_d(x)\Big]\frac{\partial H_d}{\partial x}$$

itee Ph.D
INFORMATION TECHNOLOGY ELECTRICAL ENGINEERING

Research Activity

Adopted Methodology: the IDA-PBC

For underactuated mechanichal systems the matching equation can be separated in kinetic and potential energy ones

Kinetic energy matching equation (KE-ME)

$$G^{\perp}\left[\nabla_q^{\top}[M^{-1}p]p - M_d M^{-1}\nabla_q^{\top}[M_d^{-1}p]p + 2J_2 M_d^{-1}p\right] = 0$$

Potential energy matching equation (PE-ME)

$$G^{\perp}\left[\nabla V - M_d M^{-1}\nabla V_d\right] = 0$$

Parameterize the desired mass matrix to simplify the solution of the PDEs!

Research Activity

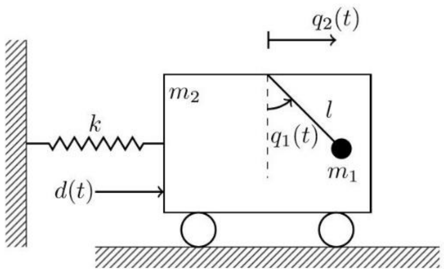
Developments

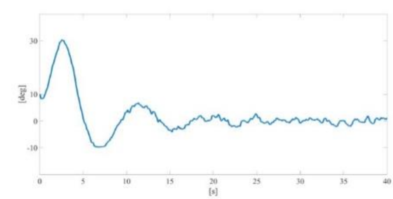
Control of the Underactuated Translational Oscillator with a Rotational Actuator System Without Explicit Solution of Matching Equations

— Underactuated mechanical system with two degrees of freedom and one actuator (rotating mass)

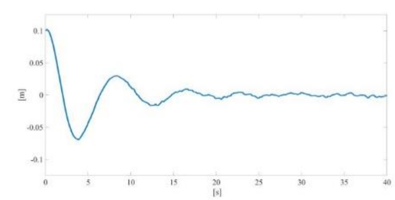
— Stabilized in the equilibrium (0,0) (the minimum fo the closed loop total energy) in presence of noise, parametric uncertainties and an exogenus disturbance

— Benchmark for upcoming applications of IDA-PBC to dynamic walking tasks





(a) Time history of $q_1(t)$.



(b) Time history of $q_2(t)$.

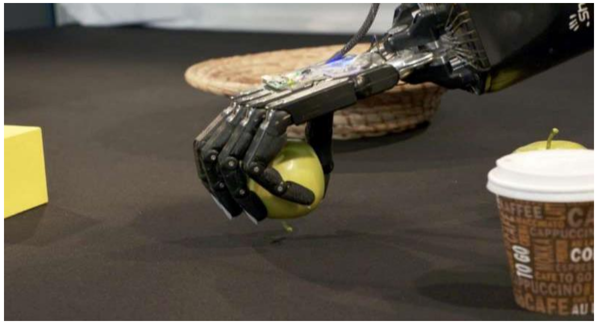
Products

Accepted Paper

P. Arpenti, D. Serra, F. Ruggiero, V. Lippiello, “Control of the TORA System through the IDA-PBC without Explicit Solution of Matching Equations”, accepted by IEEE International Robotic Computing Conference 2019, Naples, 25-27 February 2019

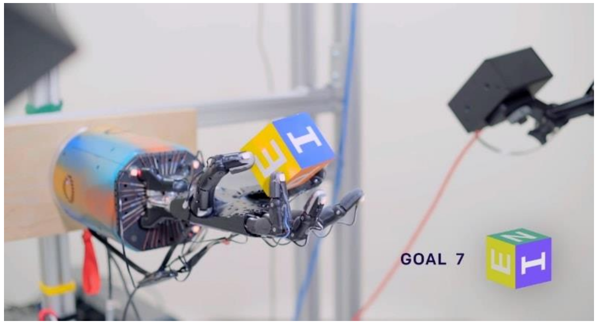
Future Application Field

Manipulation:
Static VS Dynamic



Grasping

— Object manipulated caging it between fingers



Nonprhensile **Manipulation**

— Object manipulated without caging it

IDA-PBC well suited for nonprhensile manipulation (robustness, efficiency)

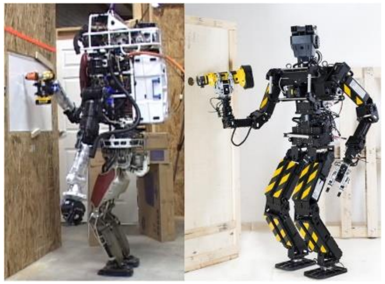
Future Application Field

Bipedal Walking

Bipedal Robots imitates humans locomotion, intrinsically underactuated

Pro

- High mobility on many different terrains
- Decoupling between lower and upper limbs facilitates manipulation tasks



Cons

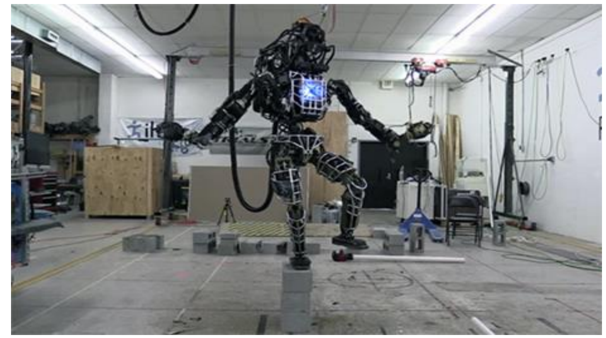
- Robustness issues (coupled nonlinear dynamics, generally unstable, and hybrid phenomena due to the switching between feet and ground)

Future Application Field

Bipedal Walking:
Static VS Dynamic

Balancing

— Stability Control



Running

— Stability + Motion Control

Future Application Field

Key Idea:
Dynamic Walking as Nonphrensile Manipulation

Similarities between grasping and walking require to optimize the contact forces between the legs and the ground a quasi-static manipulation problem

Cons

— Nor fast or efficient

Idea: exploit similarities between dynamic walking and dynamic manipulation arising from hybrid contact/non-contact conditions

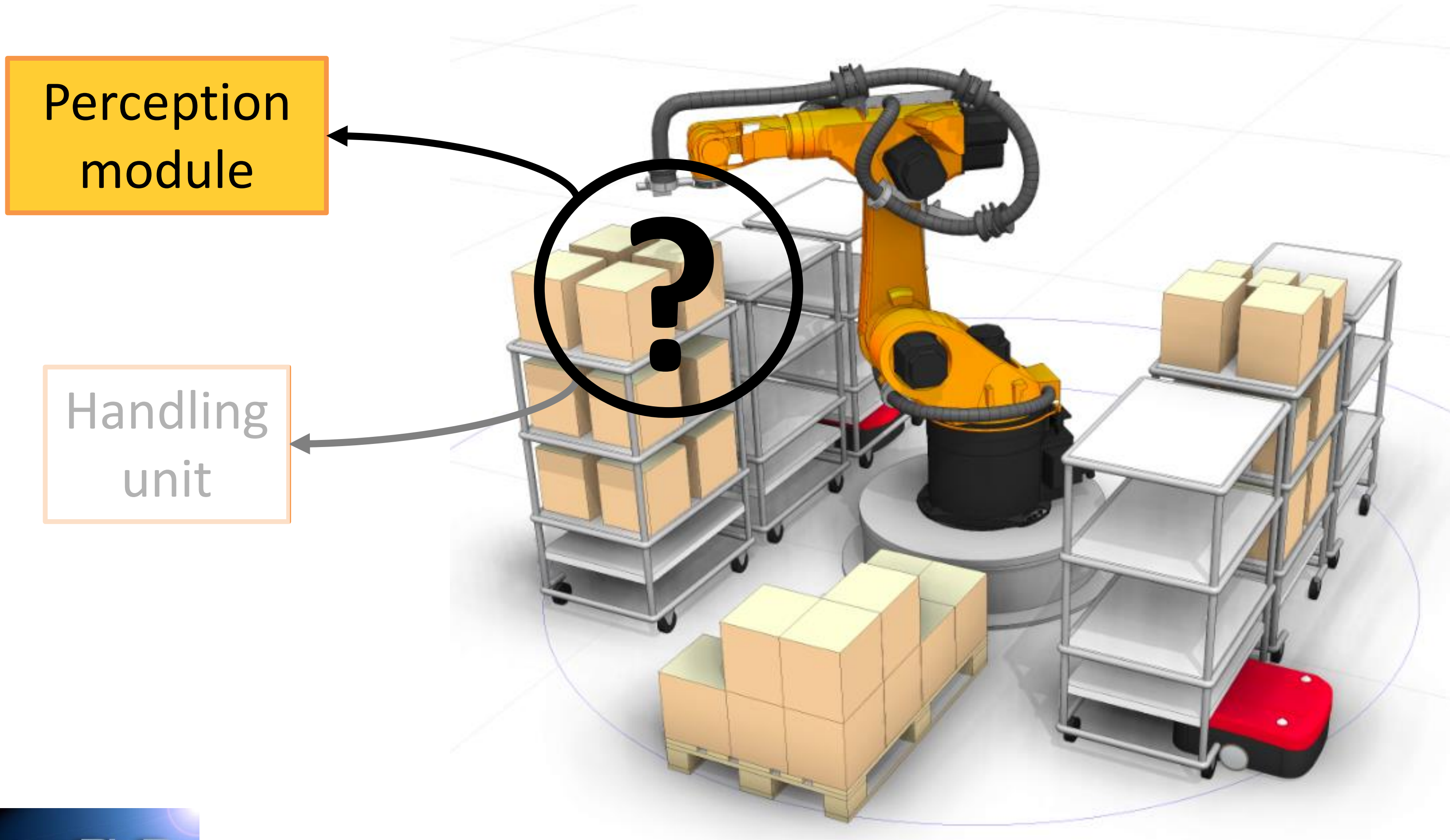
Pro

— Adapt the passivity-based controls developed for **nonprehensile** manipulation to dynamic walking to get **energy efficiency !**

investigate mapping between different domains

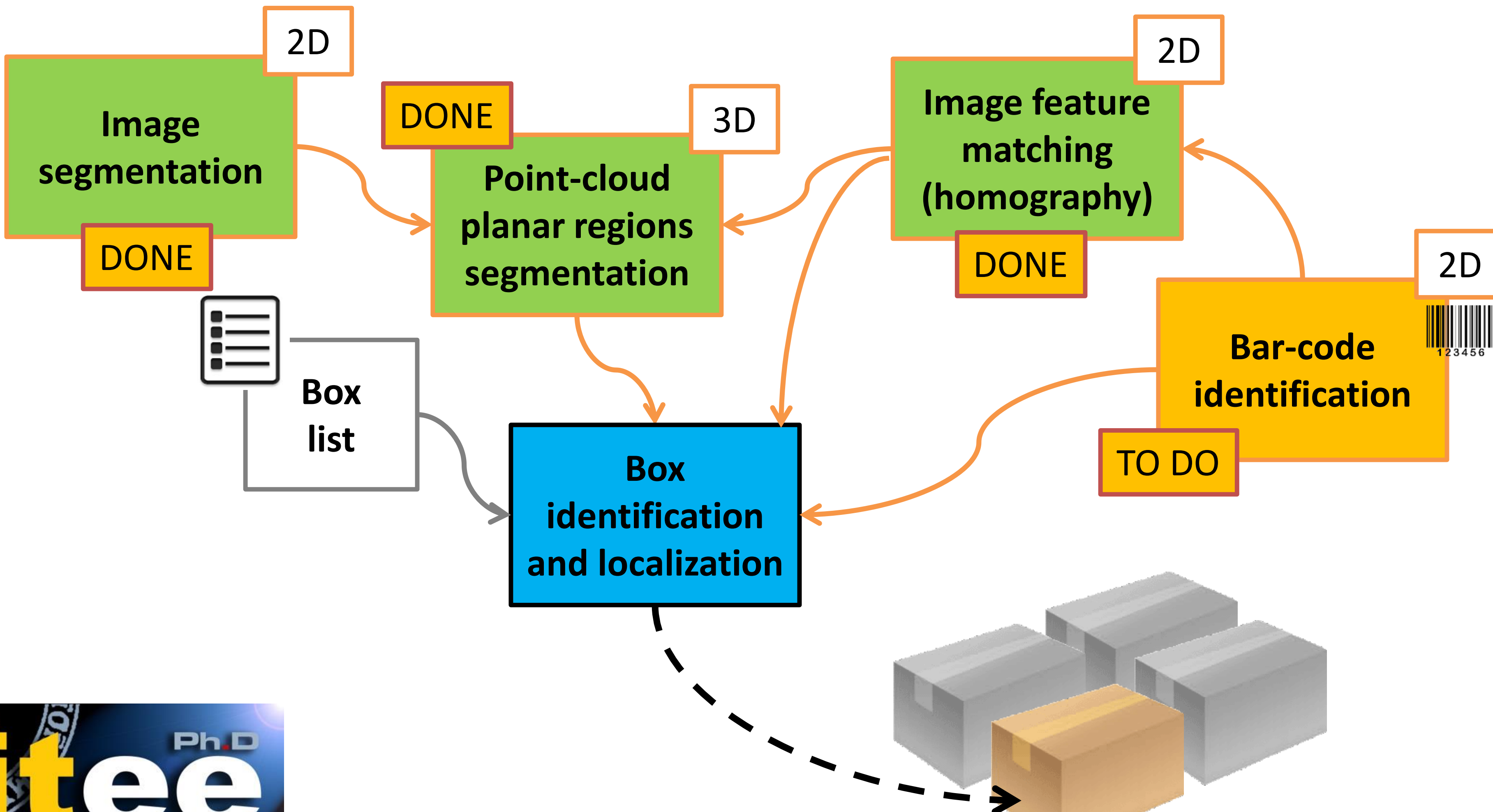
Side Research Problem

Automated Depalletization Task for Logistic Robotics



Side Research Activity

Model-Based Image Processing for Automated Depaletization



Pierluigi Arpenti

Next Years

	Credits year 1								Credits year 2								Credits year 3									
		1	2	3	4	5	6			1	2	3	4	5	6			1	2	3	4	5	6			
	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Total	Check
Modules	18	0	4	9	5	0	0	18	8							0	4							0	18	30-70
Seminars	13	1,4	1	1	3	0	0,2	6,6	4							0	0							0	6,6	10-30
Research	34	6	6	3	3	9	9	36	47							0	56							0	36	80-140
	65	7,4	11	13	11	9	9,2	61	59	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	61	180

Year	Lecture/Activity	Type	Credits	Certification	Notes
	MODULES				
1	Delay differential equations (DDEs) and their applications	Ad hoc module	3	x	
1	Introduction to modeling and control of mechanical systems with constraints	Ad hoc module	2	x	
1	Image processing for computer vision	MS module	9	x	
1	Geometric theory of soft robotics	External module	4	x	
	SEMINARS				
1	Dynamic control: mathematical challenges and applications	Seminar	0,4	x	
1	Etica e intelligenze artificiali	Seminar	0,5	x	
1	Le nuove frontiere della robotica cognitiva e l'interazione uomo-robot	Seminar	0,5	x	
1	Razionalità limitata nell'uomo e nella macchina	Seminar	0,6	x	
1	The age of human-robot collaboration	Seminar	0,4	x	
1	IBM:Q: building the first universal quantum computers for business and science	Seminar	0,8	x	
1	How does mathworks accelerate the pace of engineering and science	Seminar	0,2	x	
1	Domains of attraction and manifolds in a gear model	Seminar	0,2	x	
1	Adaptive control systems: methodologies for analysis and synthesis	Doctoral School	1,5	x	
1	Optimization methods for decision making over networks	Doctoral School	1,5	x	

Thank You