Master of Science in **Control Engineering**  
Laurea Magistrale in **Ingegneria Automatica**

www.diag.uniroma1.it/~automatica

Presentation to the students  
September 21, 2016
“Automatica”

αυτώς, "by itself", ματώς, "task", τική, "technique/study"

• **Control Engineering** (Ingegneria Automatica) deals with the bulk of engineering methods and technologies for the supervision, automation, and real-time control of dynamical systems

• an automatic control system enables to impose, in autonomous mode and using the robust properties of feedback, a desired behavior to physical devices and processes so as to guarantee
  • high performance (precision, speed, comfort, reliability, quality of service)
  • energy savings (reduction of operating costs, optimal use of primary goods)
  • improved safety, lower impact on the environment

• a **Control Engineer** is responsible for the design, realization, optimization and conduction of automatic control systems for industrial plants and other processes/systems of different nature and functionality

• use of descriptive (mathematical, cognitive) models, measurements and information acquired from sensors, and actuators to execute commands
Feedback control

- human example: locomotion based on visual feedback
- automatic example: humanoid robot guided by a camera

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“Swing-up” of a double inverted pendulum

specific control strategy  
(energy pumping + local PID)

nonlinear control

a similar control technique is used also for the stabilization of walking motion in humanoid robot!

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Automatic control and mechatronics

micro/nano actuators

periodic oscillations are induced by electro-static forces that are controlled by an AC voltage applied between the silicon substrate and the aluminum electrodes

~$10^2$ point-to-point moves per second
Applications of control systems

- Generation and distribution of energy (smart grids)
- Control of continuous industrial processes (e.g., chemical)
- Green energy management
- Service robotics and industrial automation

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Applications of control systems

Automotive (ABS, ESP, automatic parking)

Aeronautics (fly-by-wire)

Astronautics (optimal control, satellite attitude, space robotics)

Navigation (auto pilot)

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Applications of control systems

Control of artificial prostheses

LVAD = Left Ventricular Assist Device

Models of biological systems

Feedback mechanisms for regulation of: body temperature, blood pressure, glucose levels, cellular interactions ...

Robotic surgery (daVinci system)

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A “table” with multiple diners

**models**
- mathematical
- physical, chemical, ...
- economic

**components**
- sensors and actuators
- PC, DSP, μ-processors
- local/wireless networks

**engineering**
- user requirements
  - objectives, costs, constraints
- design
- simulation
- programming
- implementation

**technologies**
- computer science
- electronics
- mechanics
- electrotechnics
- telecommunication

Master of Science in Control Engineering
Courses of study at Sapienza

**Bachelor in Computer Science and Control Engineering**
- Italian name: Laurea in Ingegneria Informatica e Automatica
- 3 years, 180 credits, 20 exams
- Curriculum in Automatic Control (one out of three)
- Final work (3 credits)

**Master of Science in Control Engineering**
- Italian name: Laurea Magistrale in Ingegneria Automatica
- 2 years, 120 credits, **12 exams**
- Cooperation of the two Schools of Engineering (I3S + ICI)
- Theoretical and lab activities (control of networks, robotics)
- Final work (30 credits = internship + master thesis)

**PhD in Automatic Control, Bioengineering and Operations Research**
- 3 years of research activity
- Possibility of spending up to 1 year abroad
- Original PhD thesis
Laurea in Ingegneria Informatica e Automatica  
Bachelor curriculum in “Automatica”

First year (in common)
- Analisi matematica I (12 cfu)
- Geometria (6 cfu)
- Fondamenti di informatica I (12 cfu)
- Fisica (12 cfu)
- Tecniche di programmazione (6 cfu)
- Calcolo delle probabilità e statistica (6 cfu)
- Ricerca operativa (9 cfu)
- Idoneità lingua straniera (3 cfu)

Second year
- Programmazione orientata agli oggetti (6 cfu)
- Telecomunicazioni (9 cfu)
- Teoria dei sistemi (6 cfu)
- Analisi matematica II (6 cfu)
- Sistemi di calcolo (12 cfu)
- Controlli automatici (9 cfu)
- Elettrotecnica (6 cfu)
- Modellistica e simulazione (9 cfu)

Third year
- Automazione (9 cfu)
- Controllo e gestione delle reti (6 cfu)
- Elettronica (6 cfu)
- Economia e organizzazione aziendale (9 cfu)
- Laboratorio di automatica (6 cfu)
- Esami a scelta dello studente (12 cfu)
- Prova finale (3 cfu)

access to M.Sc. in Control Engineering is straightforward when coming from this bachelor course

in general, **96 credits are needed**
in some coded scientific disciplines (SSD):
- any ING-INF
- many ING-IND
- also MAT, FIS, CHIM

≥ 9 credits in the domain of Automatic Control (ING-INF/04) are recommended
Curriculum of the Master
(our two-year course of study is fully active since 2014-15)

• 2 mandatory core courses of 12 cfu [in 1st year] 24 cfu
  - Nonlinear systems and control
  - System identification and optimal control
    - taught during both semesters
• 6 other core courses to be chosen among 9 (group B) 36 cfu
• 3 completing courses to be chosen among 7 (group C) 18 cfu
• 1 or 2 free choices 12 cfu
  - either in groups B/C or from any other course offered at Sapienza
  - typically, in 2nd year
• internship (6 cfu) + master thesis (24 cfu) [in 2nd year] 30 cfu

• total (approx 60 cfu/year) = 120 cfu
• 12 exams as a whole
  - courses of free choice count always as 1 exam

  cfu (= credito formativo universitario) ⇒ 1 credit = 8h of lectures

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# Tailoring your curriculum

<table>
<thead>
<tr>
<th>Group B: choose 6 out of 9 (36 cfu in total)</th>
<th>year</th>
<th>sem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process automation</td>
<td>1</td>
<td>I</td>
</tr>
<tr>
<td>Robotics I</td>
<td>1</td>
<td>I</td>
</tr>
<tr>
<td>Robust control</td>
<td>1</td>
<td>I</td>
</tr>
<tr>
<td>Multivariable feedback control</td>
<td>1</td>
<td>II</td>
</tr>
<tr>
<td>Robotics II</td>
<td>1</td>
<td>II</td>
</tr>
<tr>
<td>Control of communication and energy networks</td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td>Digital control systems</td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td>Dynamics of electrical machines and drives</td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td>Vehicle system dynamics</td>
<td>2</td>
<td>II</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group C: choose 3 out of 7 (18 cfu in total)</th>
<th>year</th>
<th>sem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous and mobile robotics</td>
<td>1</td>
<td>II</td>
</tr>
<tr>
<td><em>Robotics II</em></td>
<td>1</td>
<td>II</td>
</tr>
<tr>
<td>Computer and network security</td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td><em>Control of communication and energy networks</em></td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td><em>Digital control systems</em></td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td>Machine Learning</td>
<td>2</td>
<td>I</td>
</tr>
<tr>
<td>Control of autonomous multi-agent systems</td>
<td>2</td>
<td>II</td>
</tr>
</tbody>
</table>

*Three courses appear in both groups B and C.*
Study plan
your personal choice of a curriculum of exams
= “percorso formativo”

- study plan is prepared and submitted on-line via Infostud
- it includes
  1. which courses you actually choose from the two optional groups in the “Manifesto”
  2. which courses you select of free choice (any offered at Sapienza)
  3. pay attention in which year you place a course (few options)
- plan must be submitted before registering to the single exams (October 15, 2016 - March 30, 2017)

www.uniroma1.it/studenti/infostud

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Dynamic systems and their description in Simulink (for simulation purposes), taking some simple electro-mechanical systems and their controls as reference.


see doc on web site
http://www.diag.uniroma1.it/~automatica/?p=procedure/ammissione&l=en
Browsing the web site to find most of the information you need

www.diag.uniroma1.it/~automatica

Master of Science in Control Engineering
More information

• rapidly growing course of study (since rebirth in 2013-14), with relatively large involvement of national and international students
  – 2013-14: 13 new students (0 with foreign degree)
  – 2014-15: 23 new students (7 with foreign degree)
  – 2015-16: 42 new students (16 with foreign degree, 7 from other Italian universities)
  – 2016-17:...

• personalized tutoring system (since 2015-16: 5 students/instructor)
• student honors program (percorso di eccellenza): 4 positions in 2016-17
• mobility Erasmus+ (also, various partners in European research projects)
• possible Italian-french double degree
• contacts with local SMEs & industrial groups for internship and thesis

Master of Science in Control Engineering
Laboratories

Students of the Master of Science in Control Engineering can develop their thesis (or perform their internship) in the following DIAG laboratories. They may also collaborate to research activities on systems, networks, and robot control that are being carried out there by professors, researchers, and PhD students.

<table>
<thead>
<tr>
<th>Laboratory Name</th>
<th>Web Page</th>
<th>Area</th>
<th>Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Control Laboratory</td>
<td>[Link]</td>
<td>DIAG Via Anesto 25 A-215 (second floor) 06 77274 037</td>
<td>Prof. Francesco Dalli Priscoli dellipriscoli [at] diag.uniroma1.it</td>
</tr>
<tr>
<td>Robotics Laboratory</td>
<td>[Link]</td>
<td>DIAG Via Anesto 25 S-218 (basement) 06 77274 158</td>
<td>Prof. Giuseppe Oriolo oriolo [at] diag.uniroma1.it</td>
</tr>
<tr>
<td>Systems and Control Laboratory</td>
<td>[Link]</td>
<td>DIAG Via Anesto 25 S-217 (basement) 06 77274 159</td>
<td>Prof. Paolo Di Giambardino digiambardino [at] diag.uniroma1.it</td>
</tr>
</tbody>
</table>

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task planning and control of robotic systems

- **DIAG Robotics Lab**
- established in 1987
- [www.diag.uniroma1.it/labrob](http://www.diag.uniroma1.it/labrob)
- [www.youtube.com/user/RoboticsLabSapienza](http://www.youtube.com/user/RoboticsLabSapienza)
- located in S-218 (basement)
- several EU research projects (Framework VI-VII, Horizon 2020)
oldies, but goldies (1994-2004)

- automatic parking of wheeled mobile robots
- accurate execution of arbitrary trajectories

3 video

online tracking of a mobile target from visual feedback (many other applications!)

video

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Motion planning in cluttered environments

video
Exploration and mapping of unknown environments

- single robot with laser sensor
- team of Khepera robots (decentralized control with limited communication range)

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Control of UAV (drones)

- heighth control using ultrasonic sensor
- tracking of ground vehicle with on-board vision system

**Hummingbird quadrotor**

**UAV** = Unmanned Aerial Vehicle

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Motion control of a locomotion platform for the physical exploration of VR worlds

CyberWalk platforms for natural and unconstrained locomotion in VR

- Visual feedback
- Walker motion
- Walker
- Platform
- Platform control
- Centering strategy

control law: feedback using also a dynamic observer + feedforward

video

small-scale ball array CyberCarpet

full-scale 2D omnidirectional treadmill

CyberCarpet

FP6 CyberWalk (2005-08)
Control of the CyberWalk locomotion platform

CyberWalk Integration Test
Tracking - Virtual Environment

Simon Haegler, ETH Zurich
Thanks to:
Jan Souman, Ilja Frissen, MPG Tuebingen
Paolo Robuffo Giordano, UOR
May 2007

Video attachment to IROS’09 paper
Control Design and Experimental Evaluation of the 2D CyberWalk Platform

A. De Luca, R. Nattone, P. Robuffo Giordano and H. H. Bülthoff

Dipartimento di Informatica e Sistemistica Max Planck Institute for
Università di Roma “La Sapienza” Biological Cybernetics

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Control system “architecture” of the 2D CyberWalk platform

Image processing

VR visualization while walking

Platform control

$\theta_x \theta_y$

Encoder

$VICON$ system

$x \ y \ \theta_w$

$\nu_x \ \nu_y$

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Cyberith platform and remote control (telepresence)

video

Oculus Rift HMD

video

passive but sensorized!

NAO humanoid (virtual in VREP, real in the lab)
Accurate and feasible motion control using redundancy

video

Control of Redundant Robots under Hard Joint Constraints: Saturation in the Null Space

Fabrizio Flacco  Alessandro De Luca  Oussama Khatib

Robotics Lab, DIAG Sapienza Università di Roma
Artificial Intelligence Lab Stanford University

July 2014

satisfying robot actuation constraints: joint range limits; max joint velocity, acceleration, and torque

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Safe control of physical human-robot interaction

sensorless (!) collision detection and reaction

video

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Safe control of physical human-robot interaction

collision avoidance for coexistence

human-robot collaboration
Sensor-based control of NAO humanoid robot

guided (also, hand-guided) through the exchanged forces...

vision-driven...

Manual Guidance of Humanoid Robots without Force Sensors: Preliminary Experiments with NAO
M. Bellaccini, L. Lanari, A. Paolillo, M. Vendittelli
Robotics Lab, DIAG Sapienza Università di Roma
September 2013

Video
Haptic control in medical applications (needle steering)

KUKA LWR holding the needle

Omni Geomagic haptic device

video
smart grids, e-vehicle routing, car sharing/pooling, mobile and fixed networks, critical infrastructures, QoS/QoE in heterogeneous networks & Future Internet, ...

- **DIAG Network Control Lab**
- **labreti.ing.uniroma1.it**, located in A-215 (second floor)
SMART CITY

• a “hidden” but ubiquitous role of automatic control systems in all these complex systems
SMART HOME Automation

- integration of sensor networks for energy management
- connection of domestic/local networks with regional/national smart grids so as to optimize energy demand/offer
- display of information to users allows informed management of own energy consumption
- tele-control and video-surveillance (electricity, heating, safety, ...)

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SMART HOME e-Health

**tele-medicine**

- simple installment of sensors and their automatic reconfiguration
- remote monitoring of the health status of patients and/or old people
- decision support systems for medical diagnostics and alarm control
SMART MOBILITY

Trip PLANNING and optimal ROUTING for e-MOBILITY

Control strategies for RECHARGING for e-MOBILITY
Control for aerospace and space exploration

www.diag.uniroma1.it/~syscon

DIAG Systems and Control Lab
(basement S-217)
A sample master thesis in Control Engineering

• Director of the course: Alessandro De Luca (deluca@diag.uniroma1.it) ⇒ office hours for students: Tuesday 12:00-13:30 (or by email)

• Student office: Giuseppina Melita (melita@...), c/o DIAG, room B-001 (ground floor)

• Foreign students help desk: Ester Latini (ecs-int@...), room SORT (next to A7)

• Student representative: Antonio Rabezzano (new elections soon for 2 representatives)

• Web site (bilingual): www.diag.uniroma1.it/~automatica

• News: http://www.diag.uniroma1.it/~automatica/?p=news&l=en
“Power is nothing without control”

Carl Lewis in a commercial for Pirelli tyres in the early ‘90