Laurea Magistrale in Control Systems Engineering

Ruggero Carli
Angelo Cenedese
Alessandro Chiuso
Augusto Ferrante
Gian Antonio Susto
Francesco Ticozzi
Maria Elena Valcher
Welcome

Presentation of the master program in

Control Systems Engineering

• bearing the cultural inheritance of the LM in “Ingegneria dell’Automazione”
• proposing a rich spectrum of courses (with few compulsory exams)
• offering 4 new paths in the most modern and active areas of control
• featuring a final thesis project of 30 cfu
• entirely taught in English
Success Stories

- Our students found rewarding and important technical positions both in local and international companies in heterogeneous sectors, such as:
  ○ Automotive;
  ○ Automation and Robotics;
  ○ Home Appliances;
  ○ Power and Energy;
  ○ ...
- Several of our fellow students are faculties/hold positions at prestigious universities around the world.
**Success Stories: Industrial**

**Marco Todescato** - Research Scientist @ Bosch Center for Artificial Intelligence

*Thanks to the skillset in ‘Control of Dynamical Systems and Optimization’ developed during my graduate studies at DEI, I currently develop cutting-edge research solutions in the field of Artificial Intelligence in one among the top German industrial research centers.*

**Laura Dal Col** - Senior Research Engineer @ Scania Group

*I believe that my education, and especially my master degree program has given me the tools to succeed in my career: the technical knowledge and the critical mindset to attack the tasks at hand, the formalism and the logical thinking, and last but not least the international network to find support and opportunities.*
Success Stories: Industrial

Diego Romeres - Research Scientist @ Mitsubishi Electric Research Laboratories

*Thanks to the studies in control engineering I became a researcher in the prominent world of Artificial Intelligence. I develop machine learning technologies for robotic systems in a cutting-edge research laboratory.*

Michele Luvisotto - R&D Scientist @ ABB Power Grids

*Thanks to the Master degree and PhD in Control Systems Engineering I’ve acquired the competences in industrial communication systems that I employ every day to build intelligent and more sustainable electric networks.*
Success Stories: Industrial

Elisa Feltre - Software Development Engineer @ Skilled Group

*I found a welcoming and exciting environment* where new ideas are always encouraged and developed. The wide range of subjects allowed me to follow all my inclinations, which, together with my international experience, gave me the perfect set of skills for the job I love.

Giuliano Zambonin - Control Systems Engineer @ Electrolux Italia

*Thanks to my studies in Control Systems Engineering I had the opportunity to become a Control Algorithms Engineer at Electrolux to develop the new generation of household smart major appliances improving the consumer experience.*
Success Stories: Academic

Francesca Parise - Postdoctoral Research Fellow @ Massachusetts Institute of Technology

The Master in Control Engineering at UNIPD offered me the perfect combination of theoretical training and applied experiences. Advanced research projects inspired me and gave me the confidence to pursue an academic career after graduation.

Alberto Padoan - Research Associate @ University of Cambridge

The Department of Information Engineering is an incredibly fertile environment where to grow. The Control group is internationally recognised as one of the best Control Engineering schools in Europe. The degree in Control Systems Engineering taught me that theory has a very practical influence on key engineering questions.
Success Stories

- Average monthly salary one year after the graduation: 1614 €
- Several students starting collaborating with the hiring company thorough the thesis or the applied PhD
- Areas of focus in the discipline of Control:
  ○ Robotics
  ○ Machine Learning
  ○ Industrial Automation
  ○ Complex Systems
Specializations

Robotics

Machine Learning

Industrial Automation

Complex Systems
Course Catalogue

Design philosophy:

Technology is important but rapidly changing, methodology changes much slower.

⇒ Optimal balance between technological competences and deep understanding of the methods.
Course Catalogue

Common courses and activities:

- SYSTEMS THEORY 9 cfu (Year 1, Semester 1)
- MACHINE LEARNING 9 cfu (Year 1, Semester 1)
- DIGITAL CONTROL 6 cfu (Year 1, Semester 1)
- ESTIMATION AND FILTERING 6 cfu (Year 1, Semester 2)
- CONTROL LABORATORY 9 cfu (Year 1, Semester 2)

FINAL THESIS + INTERNSHIP 21+9=30 cfu

ITALIAN/ENGLISH LANGUAGE: 3 cfu
Course Catalogue

Choices (with very mild constraints)

- Mathematical Methods for Optimization
- Convex Optimization
- Mathematical Physics
- Digital Signal Processing
- Quantum Information and Computing
- Neural Networks and Deep Learning
- Measurement Architectures for Cyber-physical Systems
- Learning Dynamical Systems
- Electric Drives for Automation
- Industrial Automation
- Robotics and Control I
- Robotics and Control II
- Intelligent Robotics
- Robotics Laboratory
- Industrial Robotics

- Computer Vision
- Adaptive and Model Predictive Control
- Reinforcement Learning
- Nonlinear Systems and Control
- Big Data Computing
- Learning from Networks
- Game Theory
- Embedded Real-Time Control
- Network Systems
- Information Security
- Automata, Languages and Computation
- Systems Biology
- Control of Biological Systems
- Smart Grids
- Automotive and Domotics
- Stochastic Processes
Robots today are making a considerable impact from industrial manufacturing to healthcare, transportation, and exploration of the deep space and see...

...tomorrow, robots will become pervasive and touch upon many aspects of modern life

Goal: to provide the main mathematical competencies in the field of robotics

Main topics:

- basic concepts of robotics, kinematic and dynamic models
- advanced control schemes for industrial and mobile robots
Robots Path

Core Courses (33cfu)
- Robotics and Control 1
- Robotics and Control 2
- Convex Optimization
- Computer Vision

followed by “elective” courses (15cfu), e.g. centered on emerging subfields:

“Learning”
- Learning Dynamical Systems
- Reinforcement Learning

“Industrial”
- Electric Drives for Automation
- Embedded Real-Time Control
- Measurement Architectures for CPS

“Advanced Control”
- Nonlinear Systems & Control
- Network Systems

“Applied”
- Industrial Robotics
- Intelligent Robotics
- Robotics Laboratory
Machine Learning

TWO FACTS

(1) Unprecedented quantity and/or quality of data
(2) Modern Control Systems quest for flexibility, adaptability and robustness

- merge physical modeling/insight with data driven methods
- exploit data to design control architectures/algorithms

Control meets Machine Learning
Machine Learning Path

Core Courses (30 cfu)
Convex Optimization
Learning Dynamical Systems
Reinforcement Learning
Computer Vision

… followed by “elective” courses (18 cfu), e.g. centered on emerging subfields:

“Advanced Control”
Nonlinear Systems & Control
Robotics and Control 1
Adaptive and Model Predictive Control

“Methods and Models”
Game Theory
Neural Networks and DL
Mathematical Methods for Optimization

“Computation and measurements”
Big Data Computing
Measurements architectures for cyber-physical systems
Industrial Automation

Modern Industrial Engineering is a powerful blend of Automation – Computer Science – Telecommunication

Challenges and stars of the Industrial Revolution 4.0:

- *Cyber Physical Systems*: physical quantities are translated into data and information…

- *Human is in the loop*: the barrier between man and machine dissolves…

- *Resilience and autonomicity*: systems gain ability to recover from or adjust easily to misfortune or change…
Industrial Automation Path

**Core Courses (30cfu)**
- Convex Optimization
- Embedded Real-Time Control
- Industrial Automation
- Electric Drives for Automation

... followed by “elective” courses (18cfu), e.g. centered on emerging subfields:

**“Applied”**
- Industrial Robotics
- Computer Vision*
- Measurement Architectures for CPS

**“Disruptive”**
- Reinforcement Learning
- Information Security
- Computer Vision**
- Adaptive & MPControl

**“Methodological”**
- Learning Dynamical Systems
- Robotics and Control 1
Complex Systems

A lesson from the Covid emergency: Raw data are the starting point, models (of suitable structure) are needed to interpret them, effectively predict evolution and optimize intervention strategies!

Focus on tools to understand, model and control real-world systems and emerging technologies: Nonlinear, Networked, Biological and Quantum Systems. Learn:

How to build models from data and first principles.

How to design controls tailored to the application.

Oriented to concepts and methods, ideal preparation to work developing cutting-edge technologies and to pursue a PhD.

[Petta, Science 05]
Complex Systems Path

Core Courses (27cfu)
- Learning Dynamical Systems
- Mathematical Methods for Optimization
- Mathematical Physics

... followed by “elective” courses (21cfu), centered on emerging subfields.

Examples:

“Advanced Control”
- Nonlinear Systems & Control
- Network Systems
- Robotics and Control 1
- Learning from Networks

“Algorithms”
- Automata, Languages and Computation
- Quantum Information & Computing
- Game Theory

“System Biology”
- System Biology
- Control of Biological Systems
- Sistemi Ecologici*
Research topics

The next slides give a brief oversight of the current research interests of our group.

This may be of interest to you for various reasons:

- Topics for possible Master Theses/Stage
- Future work opportunities
- Why not a PhD in Systems and Control?
The Control and Systems Group: Faculty
# The Control and Systems Group: PhD students

<table>
<thead>
<tr>
<th>Advisor</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Ferrante</td>
<td>Reciprocal Processes, Optimal Transport, Riccati Equations</td>
</tr>
<tr>
<td>R. Carli</td>
<td>Reinforcement Learning</td>
</tr>
<tr>
<td>L. Schenato</td>
<td>Estimation and Control over Processing Networks</td>
</tr>
<tr>
<td>G.A. Susto</td>
<td>Anomaly and fault detection in Oil &amp; Gas Application</td>
</tr>
<tr>
<td>L. Schenato</td>
<td>Smart Building Automation Systems</td>
</tr>
<tr>
<td>R. Carli</td>
<td>Distributed and time-varying optimization</td>
</tr>
<tr>
<td>G.A. Susto</td>
<td>Interpretability in Machine Learning and Industry 4.0</td>
</tr>
<tr>
<td>A. Ferrante</td>
<td>Factor Analysis, dynamical graphical models, matrix decomposition</td>
</tr>
<tr>
<td>A. Cenedese</td>
<td>Dynamic modeling and soft sensing for industrial motion control</td>
</tr>
<tr>
<td>R. Carli</td>
<td>Robotics and Machine Learning</td>
</tr>
<tr>
<td>G.A. Susto</td>
<td>Data-driven approaches for Industry 4.0</td>
</tr>
<tr>
<td>M.E. Vaicher</td>
<td>Positive systems with application to social networks</td>
</tr>
<tr>
<td>G.A. Susto</td>
<td>Fairness in Machine Learning</td>
</tr>
<tr>
<td>A. Cenedese</td>
<td>Control of multi-agent and robotic networks</td>
</tr>
<tr>
<td>A. Cenedese</td>
<td>Computer Vision and Machine Learning for the industry</td>
</tr>
<tr>
<td>A. Beghi</td>
<td>Time-sensitive networking for real-time communication in industrial automation</td>
</tr>
<tr>
<td>A. Beghi</td>
<td>Industrial Ph.D @Infineon Munich</td>
</tr>
<tr>
<td>A. Beghi</td>
<td>Modeling and control of Computer Room Air Conditioning systems</td>
</tr>
<tr>
<td>A. Cenedese</td>
<td>Deep and reinforcement Learning, Industry 4.0</td>
</tr>
<tr>
<td>G.A. Susto</td>
<td>Internet-of-Things for the connections of electrical drives</td>
</tr>
<tr>
<td>A. Haghi</td>
<td>MPC-based control strategies for human-machine interaction systems</td>
</tr>
<tr>
<td>S. Vitturi</td>
<td>Distributed systems for functional safety</td>
</tr>
<tr>
<td>A. Cenedese</td>
<td>Fault detection and isolation for HVAC systems</td>
</tr>
<tr>
<td>G.A. Susto</td>
<td>Machine Learning for Information Retrieval</td>
</tr>
<tr>
<td>R. Carli</td>
<td>DeepLearning for Vision and Control</td>
</tr>
<tr>
<td>L. Schenato</td>
<td>Distributed MPC over wireless for robotic manipulation</td>
</tr>
<tr>
<td>G. Pilloniello</td>
<td>System Identification and Machine Learning</td>
</tr>
<tr>
<td>G.A. Susto</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>A. Cenedese</td>
<td>Camera Networks for the Smart City</td>
</tr>
<tr>
<td>A. Cenedese</td>
<td>Traffic Estimation and Lighting Control for Smart Mobility</td>
</tr>
<tr>
<td>A. Chiuso</td>
<td>Stochastic optimization for Deep Learning</td>
</tr>
</tbody>
</table>

Laurea Magistrale in Control Systems Engineering

20/05/2020
# The Control and Systems Group: PostDocs

## POST-DOCS & COLLABORATORS

<table>
<thead>
<tr>
<th>Advisor</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrico Picotti</td>
<td>Model Predictive Control for Automotive Applications</td>
</tr>
<tr>
<td>Tommaso Barbarioli</td>
<td>Machine Learning Approaches for Multi-Phase Flow Meters</td>
</tr>
<tr>
<td>Francesco Branz</td>
<td>Rate adaptation for control over Wi-Fi</td>
</tr>
<tr>
<td>Mattia Bruschetta</td>
<td>Motion-cueing algorithms for driving simulators</td>
</tr>
<tr>
<td>Mattia Carletti</td>
<td>Deep Learning for Industry 4.0</td>
</tr>
<tr>
<td>Chiara Favaretto</td>
<td>Biological networks dynamics</td>
</tr>
<tr>
<td>Francesco Simmini</td>
<td>Control for Smart Grids</td>
</tr>
<tr>
<td>Bin Zhu</td>
<td>Systems identification</td>
</tr>
<tr>
<td>Irene Zorzan</td>
<td>Multi-cell system biology</td>
</tr>
</tbody>
</table>

Laurea Magistrale in Control Systems Engineering

20/05/2020
Multiagent Systems & Mobile Robotics

Research on methodologies and systems

- **Ground** (AGVs) – **Aerial** (multirotors) – **Space** (nanosats) vehicles
- Design, modeling, control of new-concept platforms for improved **maneuverability** and **fail-safe** behavior
- **Extero-perception** and **Ego-estimation**: transform data streams into information
- Formations and swarms: **cooperation** with heterogeneous systems
- **Full-package**: theory, simulation and experiment
Smart Camera Networks

Research on active vision methodologies

- Multicamera systems are *pervasive* in everyday life (from industry to leisure)
- *Controllability* and *observability* issues:
  - How to control and coordinate the *information acquisition process*?
  - How to *sense the environment* with a finite number of sensors?
  - How to *maximize* quality of information and *minimize* target loss probability?
  - How to improve *system resilience* to failure or attack?
Modeling Dynamic Systems and Machine Learning

Development and analysis of novel tools for data driven modeling, with applications in several application domains, among which:

Neuroscience - effective connectivity  Robotics - inverse dynamics  Computer Vision

Development and analysis of novel tools for data driven modeling, with applications in several application domains, among which:

Neuroscience - effective connectivity  Robotics - inverse dynamics  Computer Vision

\[
x(t) = [a_{11} \quad a_{12} \quad a_{13} \quad a_{14} \quad a_{15}]
\begin{bmatrix}
0 \\
0 \\
0 \\
0 \\
0
\end{bmatrix}
\begin{bmatrix}
x(t) + w(t)
\end{bmatrix}
\]

\[
EC
\]

Forearm  Upper arm  FT sensor
Making Machine/Deep Learning viable in Engineering Applications

• Machine Learning (ML)-based applications are pervasive and it is foreseen that this trend will increase dramatically
• Many limitations are still in place (ie. adversarial examples, need for huge datasets, etc.)
• Development of approaches for ensuring ML systems with important traits like:
  - Robustness
  - Interpretability
  - Fairness
  - ...

![Machine Learning Diagram](image)
Machine Learning and Industry 4.0

- Industry 4.0 is characterized by **data**
- Machine Learning (ML)-based technologies in industry 4.0:
  - **Predictive Maintenance**
  - **Fault/Anomaly Detection**
  - **Virtual Sensors**
  - ...
- Many interesting aspects on a ML perspective: complex data format, data unbalancing, implementation constraints, need for interpretability, domain adaptation...

- Research fostered by many **collaborations** in various manufacturing areas: home appliances, machine tools, oil and gas, packaging, pharmaceutical, semiconductor, steel and foundries, ...

Laurea Magistrale in Control Systems Engineering 20/05/2020
Industrial Automation: from Computer Integrated Manufacturing to Industry 4.0, Industrial Internet of Things, and more…

Hot topics:

- Real-Time Industrial Communication Systems (wired, wireless, hybrid)
- Time sensitive networking (TSN)
- Open Platform Communication – Unified Architecture (OPC - UA)
- 5G Ultra reliable Low Latency Communication (LLC)
- Industrial Software Defined networking (SDN)
- Functional Safety Protocols
Quantum Information and Control

- New frontier of ICT...
  Quantum Technologies: Communication systems and computers based on atoms, photons, electrons;
- New computational paradigm and new information theory leads to secure communication and faster algorithms!
- EU quantum flagship: billion of euros for research;
- Google, IBM, NASA, Microsoft, ... all investing heavily.
- New control methods and tools needed!

Research on:
- Noise suppression and quantum encodings;
- Feedback and switching control;
- Modeling, estimation and simulation;
- Machine Learning & Quantum
Large-Scale Systems

Dynamical systems which can be modeled as an interconnection of a large number of subsystems (transportation systems, electric smart-grids, brain, groups of animals, etc.)

- the subsystems exhibit simple dynamics
- the overall behavior is complex, depending on the way the interconnection is built up (local interactions)

Conventional centralized techniques of modeling and control fail to give reasonable solutions

Need of distributed solutions for control, optimization, estimation and computation
Network Control Systems

Classical centralised architecture

ACTUATOR NETWORK

A
Cooperation
Coordination
Autonomy
Robustness

A

ACTUATOR

PLANT

SENSORS

CONTROLLER

SENSOR NETWORK

S
Data fusion
Redundancy
Self-healing
Clustering

S

S

S

C
Connectivity
Limited bandwidth

C
Congestion

C
Rete di comunicazione

C
Interference

C
Packet loss

C
Delays
Smart Power Grids

HOT TOPICS:
- HARMONIC COMPENSATION
- VOLTAGE STABILISATION
- LOAD PROGRAMMING
- MINIMIZATION OF POWER LOSSES
Gene regulatory networks

Genes can only exhibit two states: active (expressed) or inactive (not expressed). The status of a gene can be coded by a Boolean variable. Each gene influences the status of other genes and the interaction may be described by a logic state space model.

Gene regulatory networks can be modeled through Boolean Control Networks

\[
\begin{align*}
X(t + 1) &= F(X(t), U(t)) \\
Y(t) &= H(X(t)) \\
X(t), U(t), Y(t) &\text{ Boolean vectors}
\end{align*}
\]
Collaborative Network
Collaborative Network - Advanced Control Applications

Complex industrial systems (e.g. HVAC&R - wafer prod.):

- Virtual Metrology in process control
- Soft Sensing integration and Run-to-Run control
- Fault D-I-M: predictive maintenance
- Multiphysics modeling of components and plants

Vehicle modeling, control and simulation:

- Motion cueing for dynamic driving simulators
- Virtual vehicle driving algorithms
Collaborative Network - Advanced Control Applications

**Cubesats applications:**
- Proximity maneuvering, rendez-vous and docking
- Design of pointing laser mechanism
- Attitude estimation and control

**Control of large experimental devices (e.g. Tokamak):**
- Modeling and model reduction of physics experiments
- Design and optimization of devices and apparatuses
- Real-time estimation and control of phenomena
Laboratories

**Industrial Applications Laboratory:**
- Home appliances: learning & control
- Motors: parameter estimation & control
- PTZ camera network: cooperative control
- Driving simulator: motion cueing & control

**SPARCS Laboratory:**
- Mobile robotics laboratory
- Multirotor platforms: design, simulation, estimation/perception, control, experiments
Laurea Magistrale in Control Systems Engineering

**Laboratories**

**Industrial Application Laboratory:**
- Home appliances: learning & control
- Motors: parameter estimation & control
- PTZ camera network: cooperative control
- Driving simulator: motion cueing & control

**SPARCS Laboratory:**
- Mobile robotics laboratory
- Multirotor platforms: design, simulation, estimation/perception, control, experiments
Thank you for your attention!

Questions?

More info at:
https://lauree.dei.unipd.it/lauree-magistrali/control-systems-engineering/