Laurea Magistrale in Control Systems Engineering

Ruggero Carli

Angelo Cenedese

Alessandro Chiuso

Giulia De Pasquale

Augusto Ferrante

Gian Antonio Susto

Francesco Ticozzi

Maria Elena Valcher

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

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 - Research Manager @ 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 - Principal 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 - Research Team Manager @ Hitachi 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 - Assistant Professor @ Cornell University

*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 Assistant @ 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: 1626 €
- Several students starting collaborating with the hiring company through 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 slowlier.

$\Rightarrow$ 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

Robotics

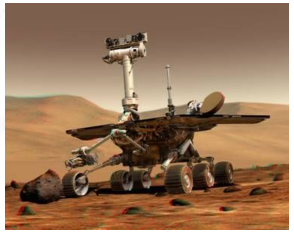
Robots **today** are making a *considerable impact* from industrial manufacturing to healthcare, transportation, and exploration of the deep space and see...

...**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



Robotics 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

"Applied"

Industrial Robotics

Intelligent Robotics

Robotics Laboratory

"Industrial"

Electric Drives for Automation

Embedded Real-Time Control

Measurement Architectures for CPS

"Advanced Control"

Nonlinear Systems & Control

Network Systems

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

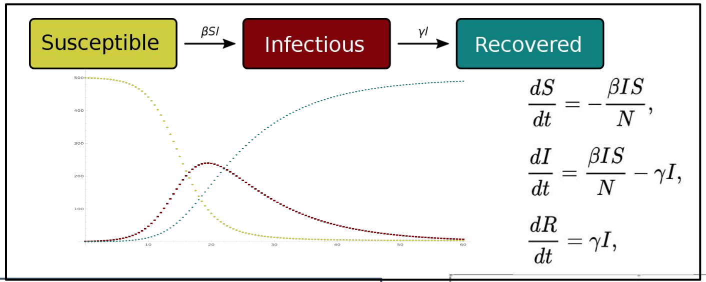
A lesson from the Covid emergency:
*Raw data are the starting point, **models** (of suitable structure) are needed to **interpret** them, effectively **predict** evolution and optimize **intervention strategies**!*

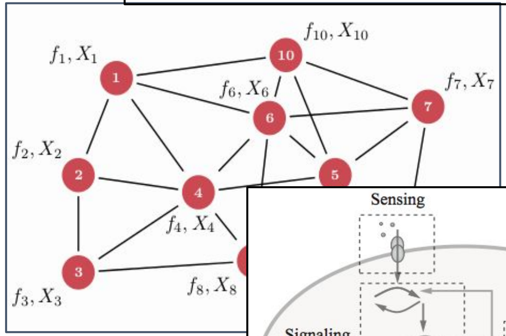
Focus on tools to understand, model and control real-world systems and emerging technologies: **Nonlinear, Networked, Biological and Quantum Systems.** Learn:

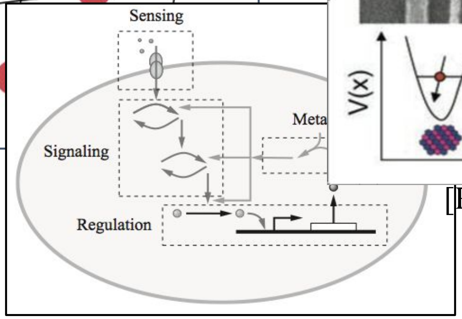
How to build models from *data* and *first principles*.

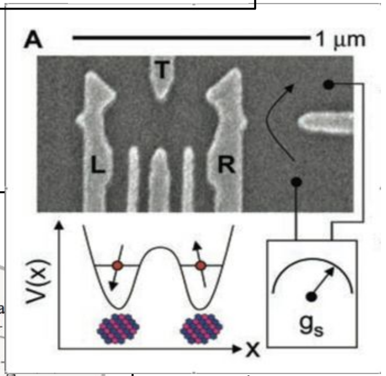
How to design controls tailored to the application.

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









[Petta, Sciene 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


A.Beghi


M.Bisiacco


R.Carli


A.Cenedese


A.Chiuso


G. Baggio


M. Rampazzo


A.Ferrante


E.Fornasini


G.Picci


G.Pillonetto


S.Pinzoni


L.Schenato


G. Michieletto


G.A. Susto


F.Ticozzi


M.E.Valcher

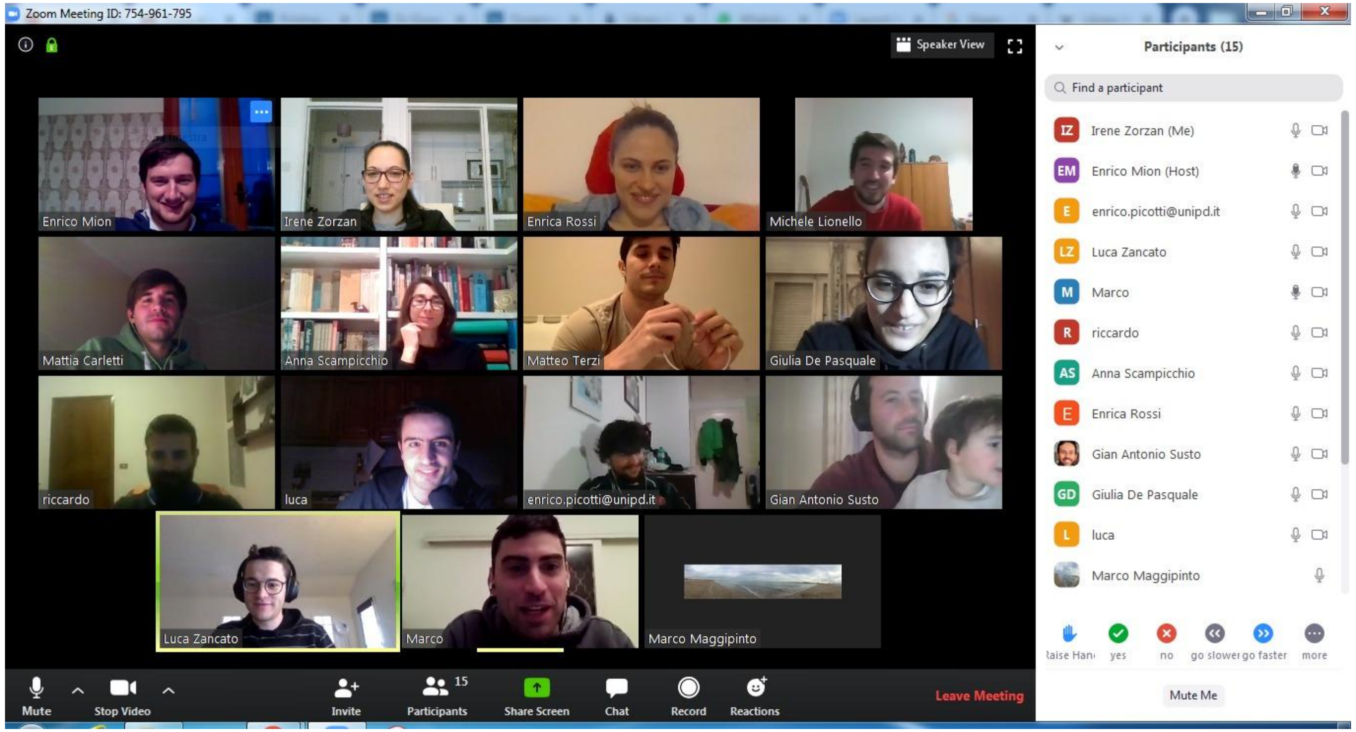

S.Vitturi


S.Zampieri


M.Zorzi


M. Bruschetta

The Control and Systems Group: PhD students



PH.D. STUDENTS

	Advisor	Subject
Daniele Alpago	A. Ferrante	*Reciprocal Processes, Optimal Transport, Riccati Equations*
Fabio Amadio	R. Carli	*Reinforcement Learning*
Luca Ballotta	L. Schenato	*Estimation and Control over Processing Networks*
Tommaso Barbariol	G.A. Susto	*Anomaly and fault detection in Oil & Gas Application*
Marco Barbiero	L. Schenato	*Smart Building Automation Systems*
Nicola Bastianello	R. Carli	*Distributed and time-varying optimization*
Mattia Carletti	G.A. Susto	*Interpretability in Machine Learning and Industry 4.0*
Valentina Ciccone	A. Ferrante	*Factor Analysis, dynamical graphical models, matrix decomposition*
Daniel Cunico	A. Cenedese	*Dynamic modeling and soft sensing for industrial motion control*
Alberto Dalla Libera	R. Carli	*Robotics and Machine Learning*
Delle Pezze Davide	G.A. Susto	*Data-driven approaches for Industry 4.0*
Giulia De Pasquale	M.E. Valcher	*Positive systems with application to social networks*
Alessandro Fabris	G.A. Susto	*Fairness in Machine Learning*
Marco Fabris	A. Cenedese	*Control of multi-agent and robotic networks*
Riccardo Fantinel	A. Cenedese	*Computer Vision and Machine Learning for the industry*
Federica Fabiana Ferro	A. Beghi	
Luca Fregonese	S. Vitturi	*Time-sensitive networking for real-time communication in industrial automation*
Natalie Gentner	A. Beghi	*Industrial Ph.D @Infineon Munich*
Michele Lionello	A. Beghi	*Modeling and control of Computer Room Air Conditioning systems*
Lissandrini Nicola	A. Cenedese	
Marco Maggipinto	G.A. Susto	*Deep and reinforcment Learning, Industry 4.0*
Alberto Morato	S. Vitturi	*Internet-of-Things for the connections of electrical drives*
Enrico Mion	A. Beghi	*MPC-based control strategies for human-machine interaction systems*
Giovanni Peserico	S. Vitturi	*Distributed systems for functional safety*
Fabio Peterle	A. Beghi	*Fault detection and isolation for HVAC systems*
Matthias Pezzutto	L. Schenato	*Cross leyer communication/control design for Drive-by-Wi-Fi*
Alberto Purpura	G.A. Susto	*Machine Learning for Infromation Retrival*
Alessandro Rossi	R. Carli	*DeepLearning for Vision and Control*
Enrica Rossi	L. Schenato	*Distributed MPC over wireless for robotic manipulation*
Anna Scampicchio	G. Pillonetto	*System Identification and Machine Learning*
Matteo Terzi	G.A. Susto	*Machine Learning*
Luca Varotto	A. Cenedese	*Camera Networks for the Smart City*
Alessandra Zampieri	A. Cenedese	*Traffic Estimation and Lighting Control for Smart Mobility*
Luca Zancato	A. Chiuso	*Stochastic optimization for Deep Learning*
Francesco Zanini	A. Chiuso	

The Control and Systems Group: PostDocs

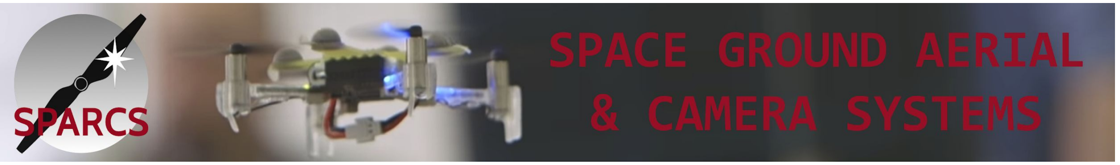
POST-DOCS & COLLABORATORS

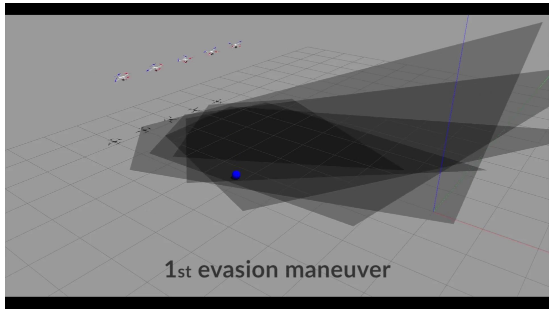
	Advisor	Subject
Enrico Picotti	A. Beghi	*Model Predictive Control for Automotive Applications*
Tommaso Barbariol	G.A. Susto	*Machine Learning Approaches for Multi-Phase Flow Meters*
Francesco Branz	L. Schenato	*Rate adaptation for control over WI-Fi*
Mattia Bruschetta	A. Beghi	*Motion-cueing algorithms for driving simulators*
Mattia Carletti	G.A. Susto	*Deep Learning for Industry 4.0*
Chiara Favaretto	A. Cenedese	*Biological networks dynamics*
Francesco Simmini	R. Carli	*Control for Smart Grids*
Bin Zhu	M. Zorzi	*Systems identification*
Irene Zorzan	L. Schenato	*Multi-cell system biology*

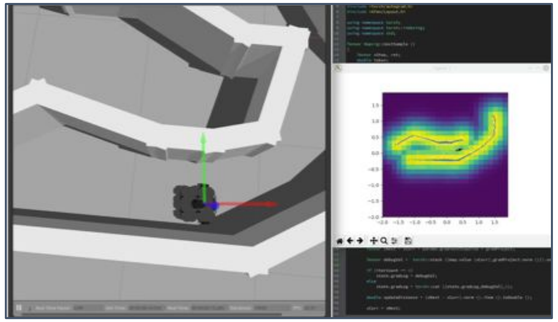
Multiagent Systems & Mobile Robotics

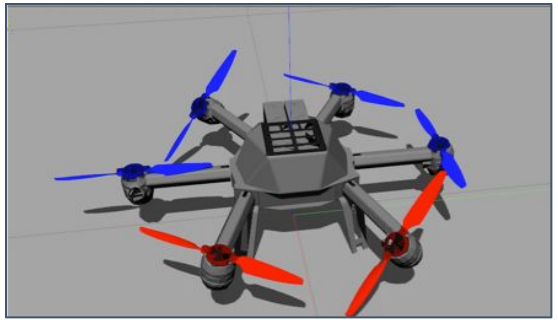
Research on methodologies and systems

- *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







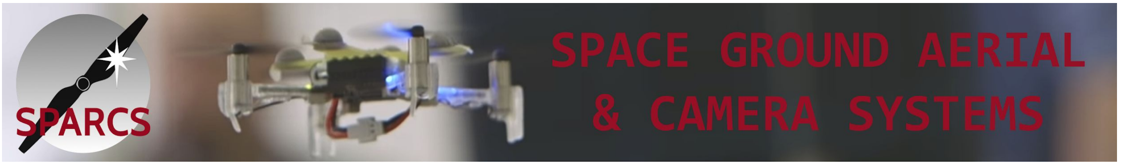


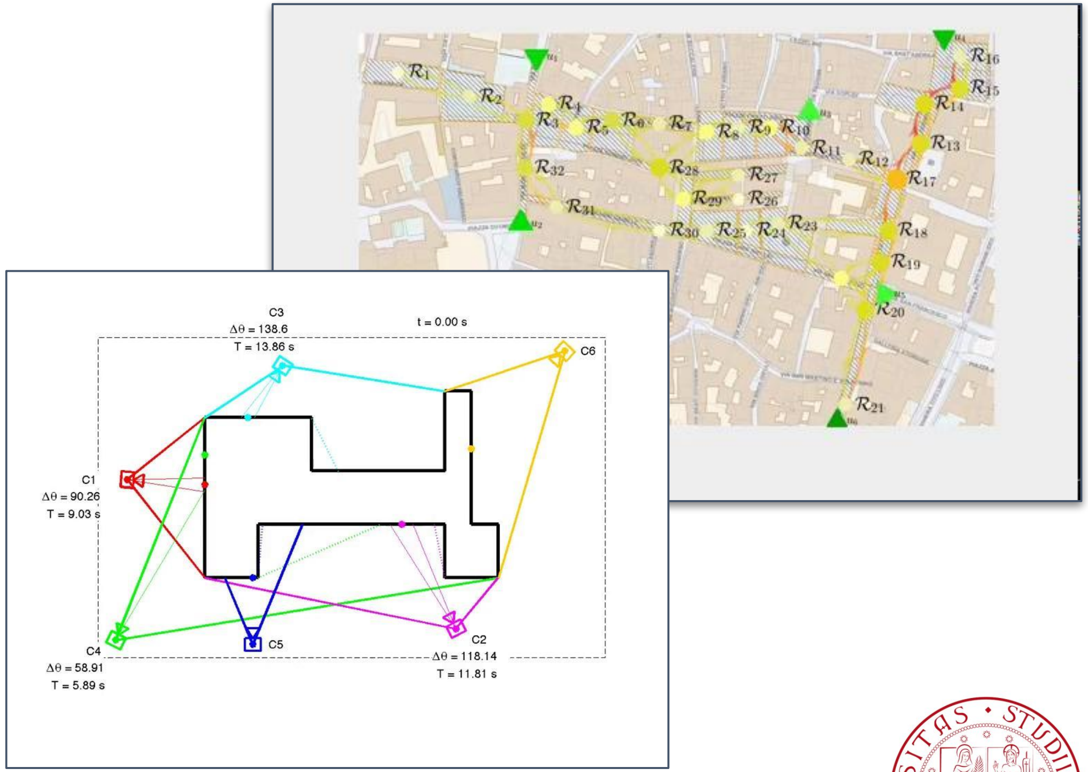
Smart Camera Networks

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?

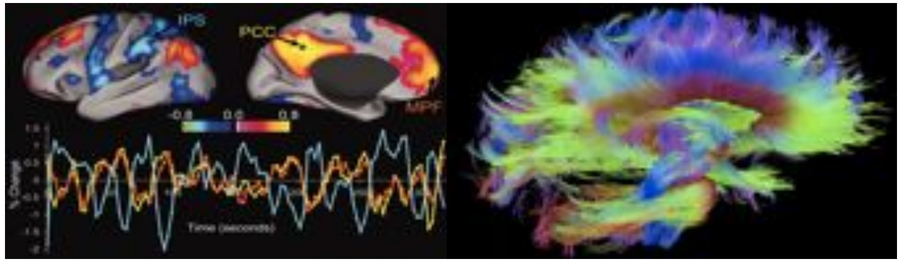


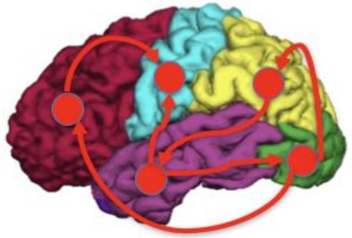


Modeling Dynamic Systems and Machine Learning

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

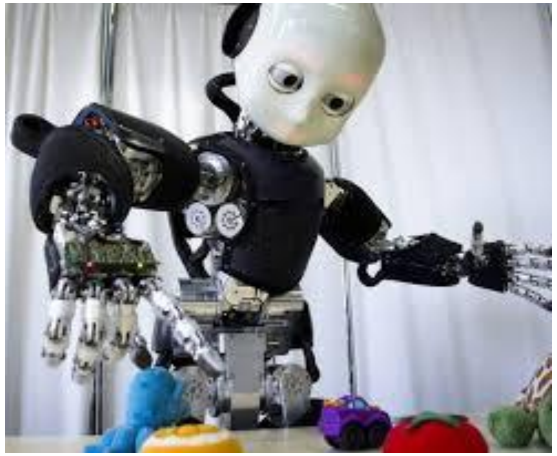
Neuroscience - effective connectivity

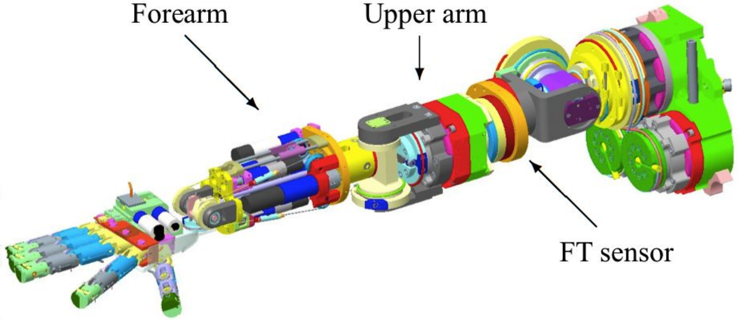




$$\dot{x}(t) = \underbrace{\begin{bmatrix} a_{11} & 0 & a_{13} & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & 0 & a_{33} & a_{34} & 0 \\ 0 & 0 & 0 & a_{44} & a_{45} \\ 0 & 0 & 0 & 0 & a_{55} \end{bmatrix}}_{\text{EC}} x(t) + w(t)$$

Robotics - inverse dynamics

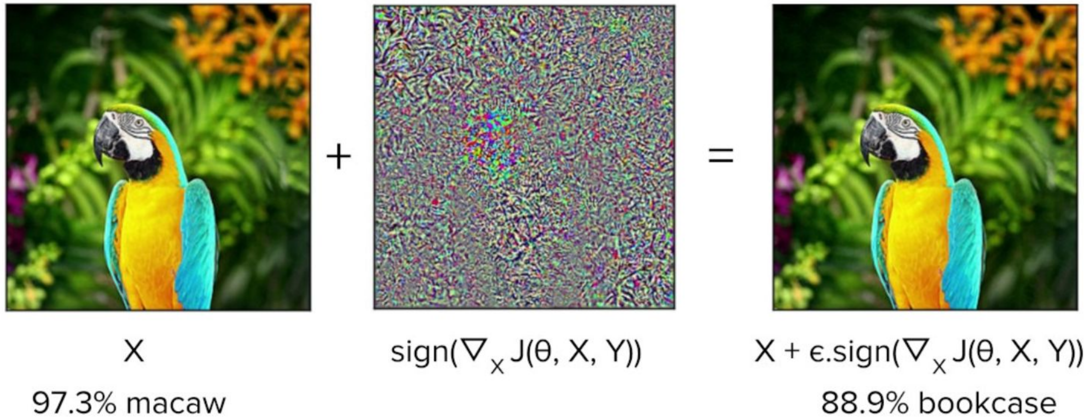




Computer Vision

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
  - ...



Industry 4.0

- Industry 4.0 is characterized by **data**
- Machine Learning (ML)-based technologies in industry 4.0:

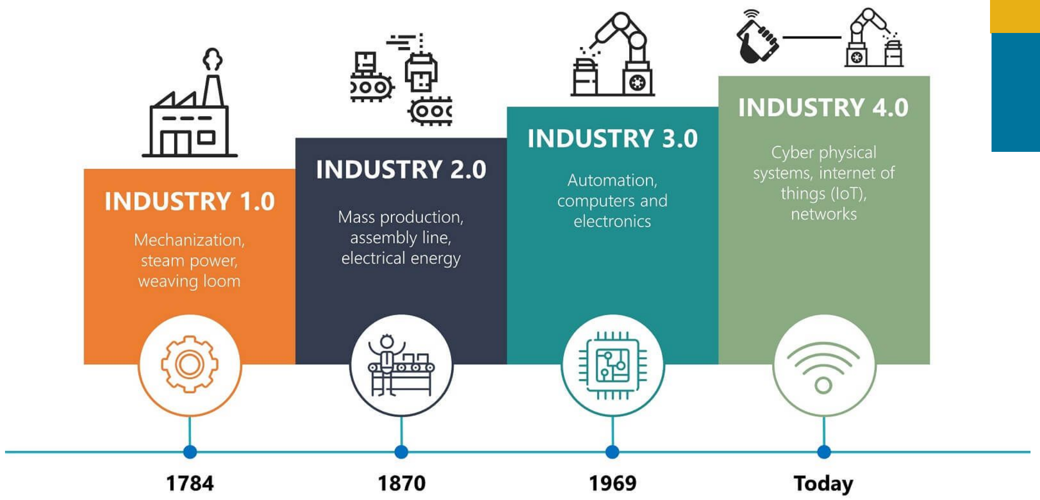
  Predictive Maintenance

  Fault/Anomaly Detection

  Virtual Sensors

  …

- Many interesting aspects on a ML perspective: complex data format, data unbalancing, implementation constraints, need for interpretability, domain adaptation...

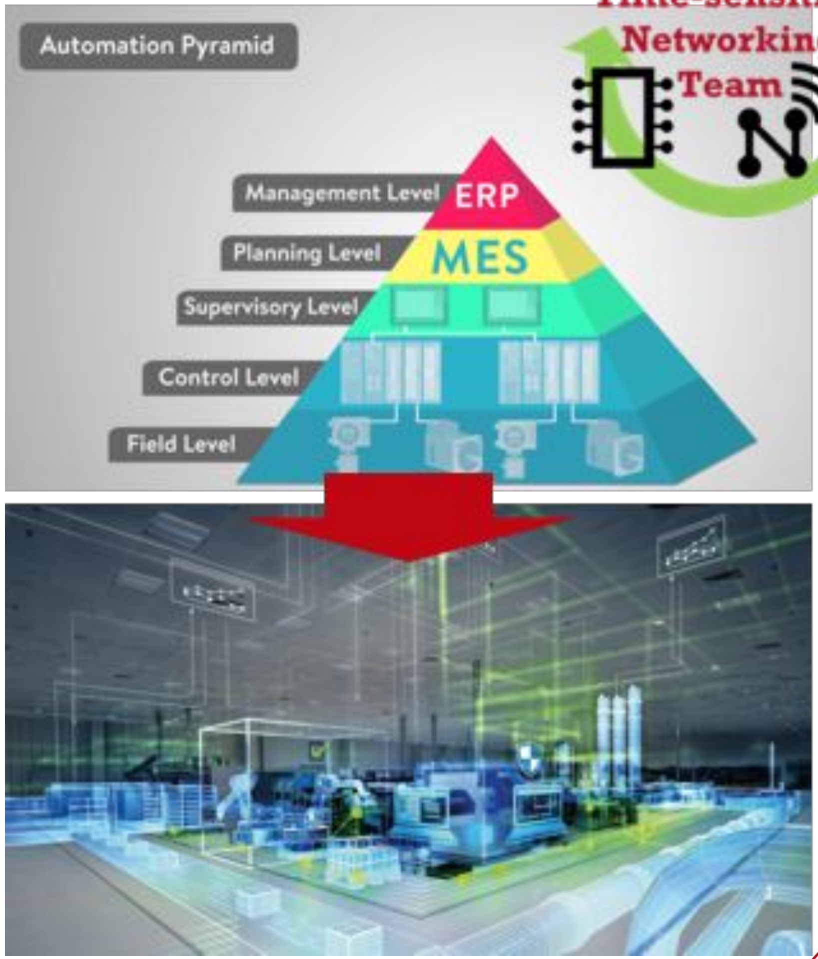


- Research fostered by many **collaborations** in various manufacturing areas: home appliances, machine tools, oil and gas, packaging, pharmaceutical, semiconductor, steel and foundries, …

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



Time-sensitive Networking Team

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!**

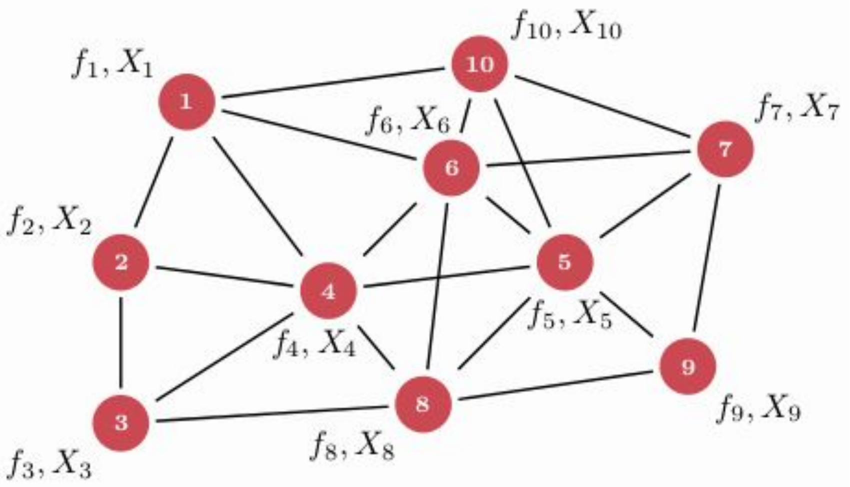
Research on:

- *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)

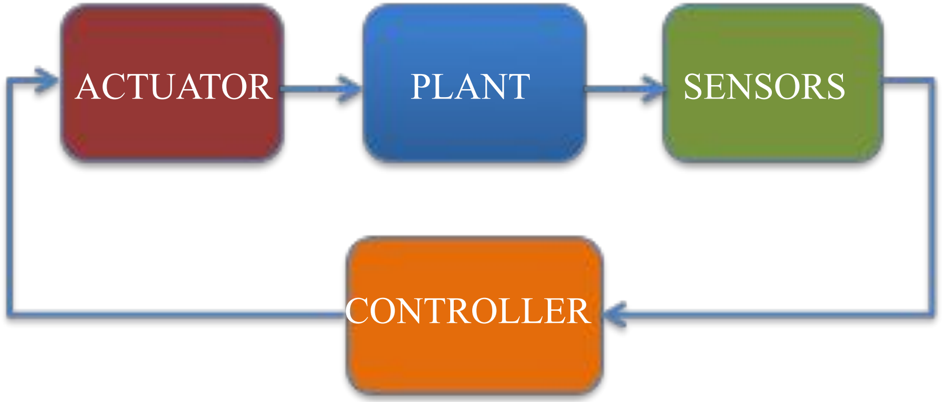


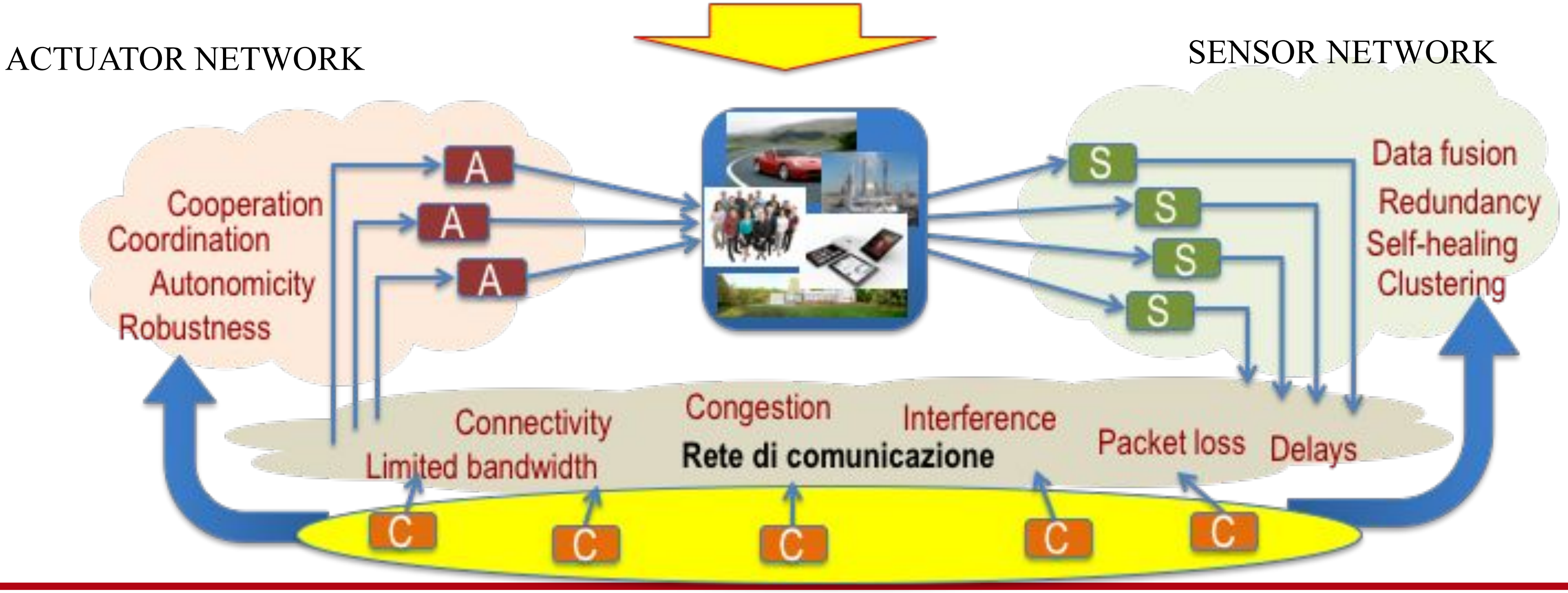
Conventional **centralized** techniques of modeling and control fail to give reasonable solutions

Need of **distributed solutions** for control, optimization, estimation and computation

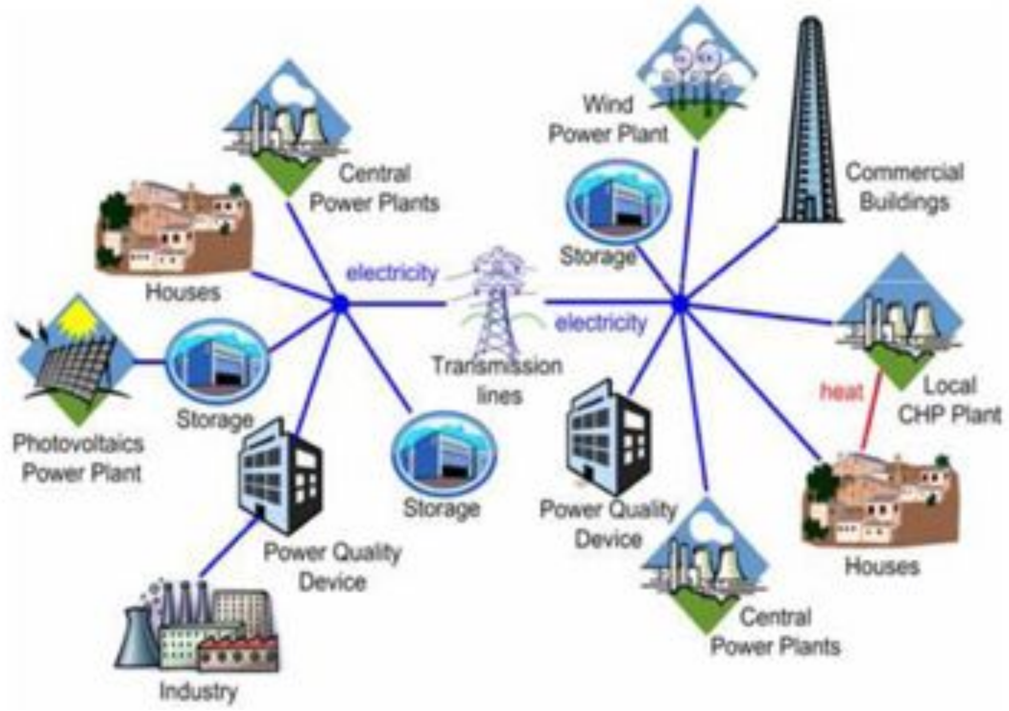
Network Control Systems

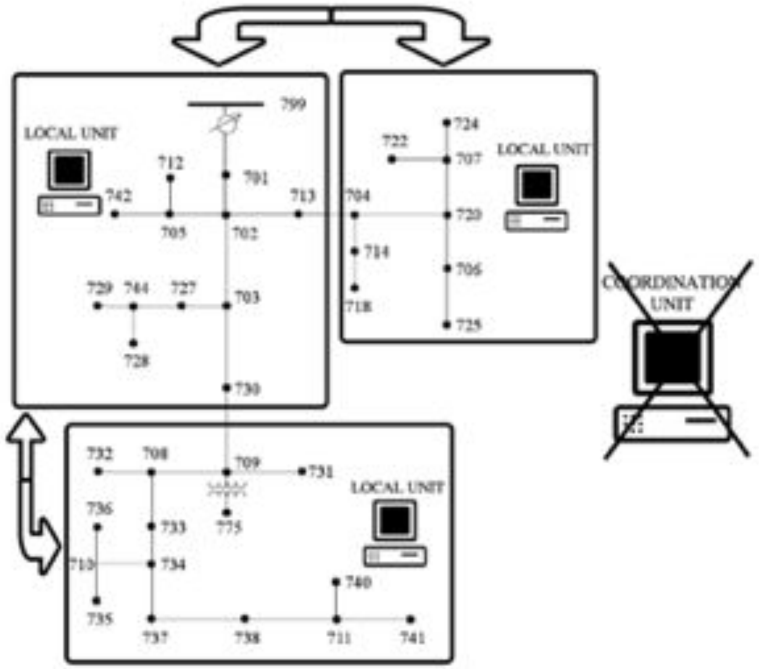
Classical centralised architecture





Smart Power Grids

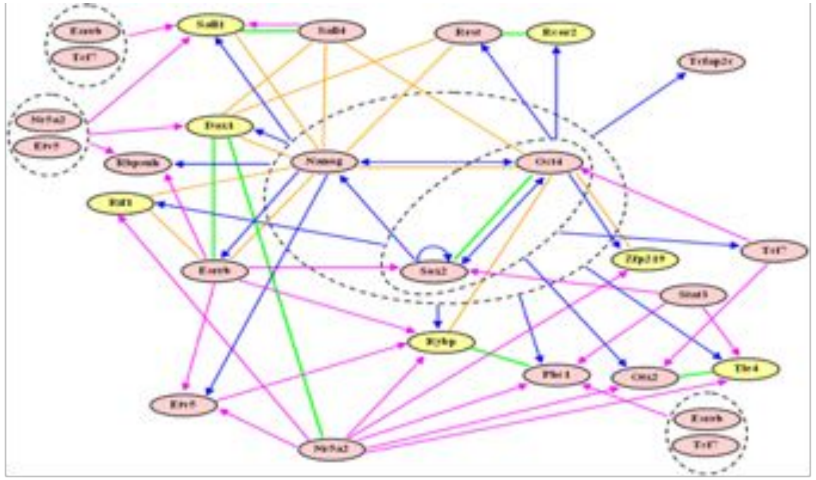




HOT TOPICS:

- HARMONIC COMPENSATION
- VOLTAGE STABILISATION
- LOAD PROGRAMMING
- MINIMIZATION OF POWER LOSSES

Gene regulatory networks



A gene regulatory network in mouse embryonic stem cells (PNAS 2007)

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

$$\begin{aligned} X(t+1) &= F(X(t), U(t)) \\ Y(t) &= H(X(t)) \end{aligned}$$

$X(t), U(t), Y(t)$ Boolean vectors

Collaborative Network

TU Delft – Delft University of Technology
Penn – University of Pennsylvania
Carnegie Mellon University
UC – University of Canterbury
Technion – Israel Institute of Technology
Queen's University Belfast
KTH
Imperial College London
ETH – Eidgenössische Technische Hochschule Zürich – Swiss Federal Institute of Technology Zurich
Massachusetts Institute of Technology
서 울 대 학 교 – Seoul National University

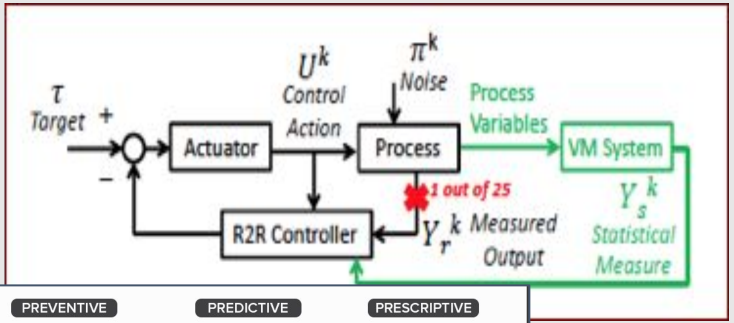
Great Ormond Street Hospital for Children – NHS Foundation Trust
Tyndall National Institute
LAAS CNRS
Consorzio RFX
Fusion for Energy
IEIIT
esa – European Space Agency
INFN – Istituto Nazionale di Fisica Nucleare
LS2N
EFDA JET

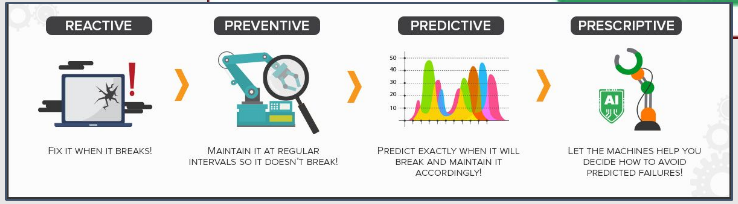
beanTech – IT moves your business
Electrolux
KRONN
Ducati Corse
SINTECO
Sibel Sistemi
WTM
RHOSS – Clima Evolution
TECHMO
STATWOLF
ST
WÄRTSILÄ
Pietro Fiorentini
BMW
VI grade
3D Everywhere
Lantech solutions
SAVE Gruppo Save
CMZ
NICON
BFT – tuned to you
Infineon
GALDI
aprilia
RI.CERT
PT – Patavina Technologies
M31
Micron
salvagnini
ADAPTICA
VIDEOTEC

Collaborative Network - Advanced Control Applications

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

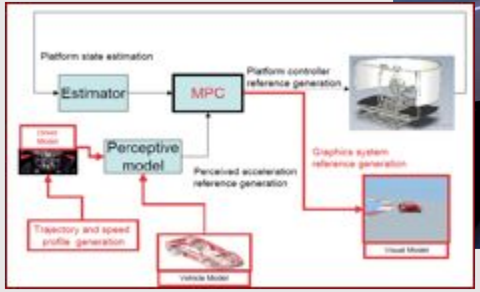
- Virtual Metrology in process control
- Soft Sensing integration and Run-to-Run control
- Fault D-I-M: predictive maintenance
- Multiphysics modeling of components and plants





Vehicle modeling, control and simulation:

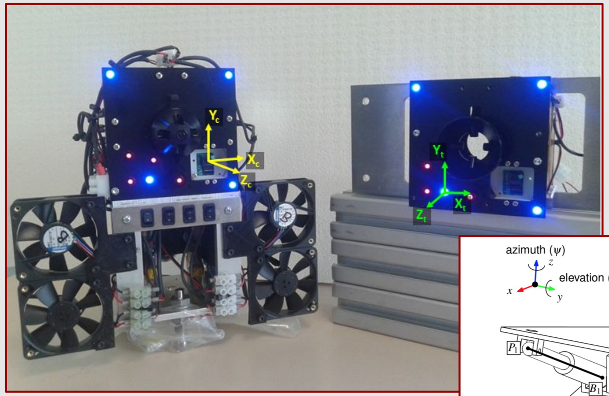
- Motion cueing for dynamic driving simulators
- Virtual vehicle driving algorithms

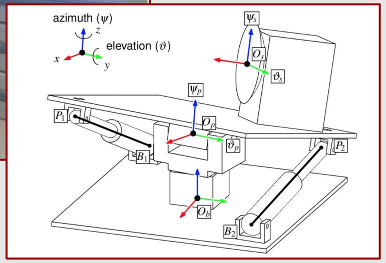


Collaborative Network - Advanced Control Applications

Cubesats applications:

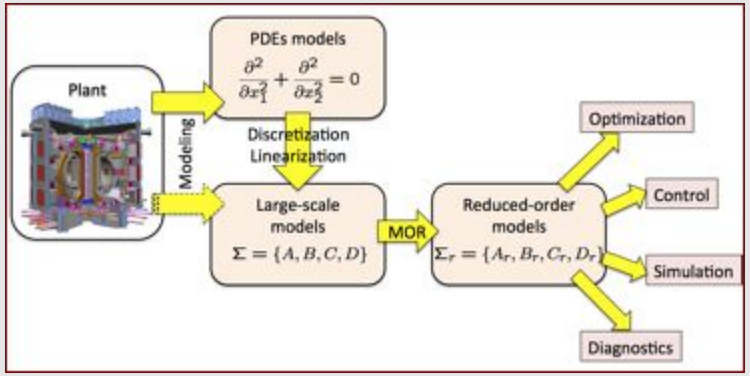
- Proximity maneuvering, rendez-vous and docking
- Design of pointing laser mechanism
- Attitude estimation and control





Control of large experimental devices (e.g. Tokamak):

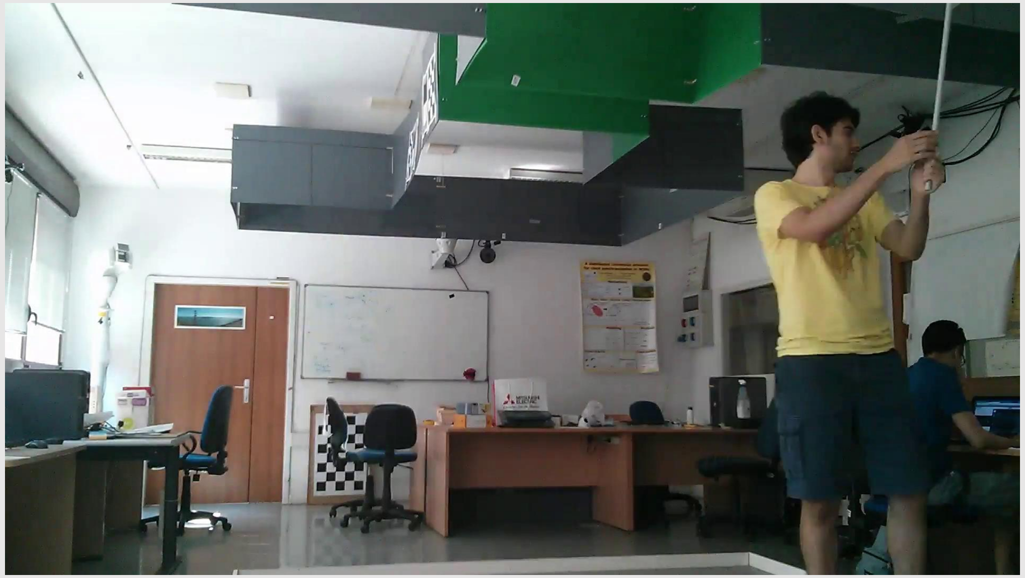
- Modeling and model reduction of physics experiments
- Design and optimization of devices and apparatus
- Real-time estimation and control of phenomena



Laboratories

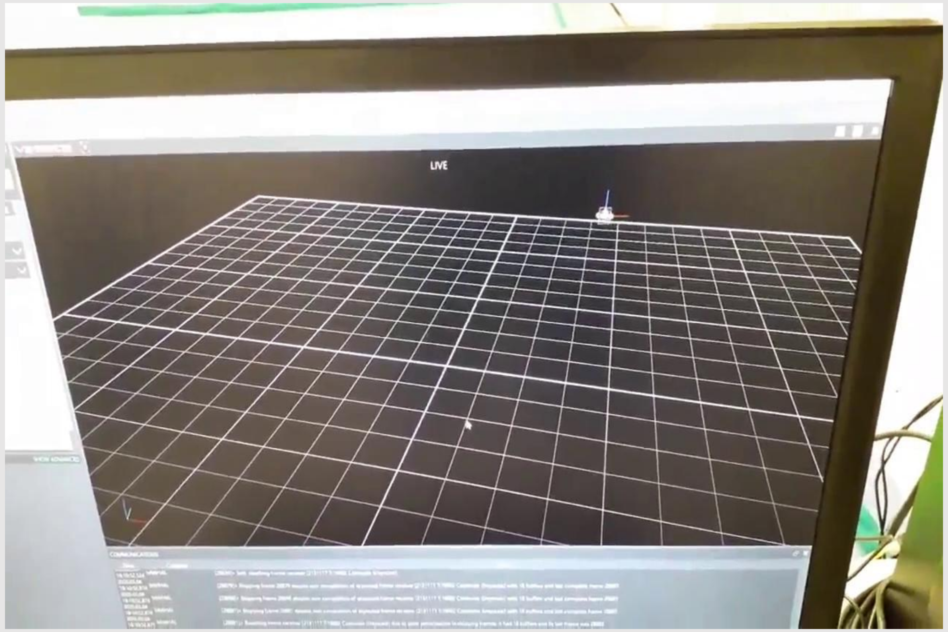
Industrial Applications Laboratory:

- 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



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A Former Master Student Experience

Thank you for your attention!

Questions?

More info at:

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