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Project Area 6:
Robotics and Control Systems

Research Fields

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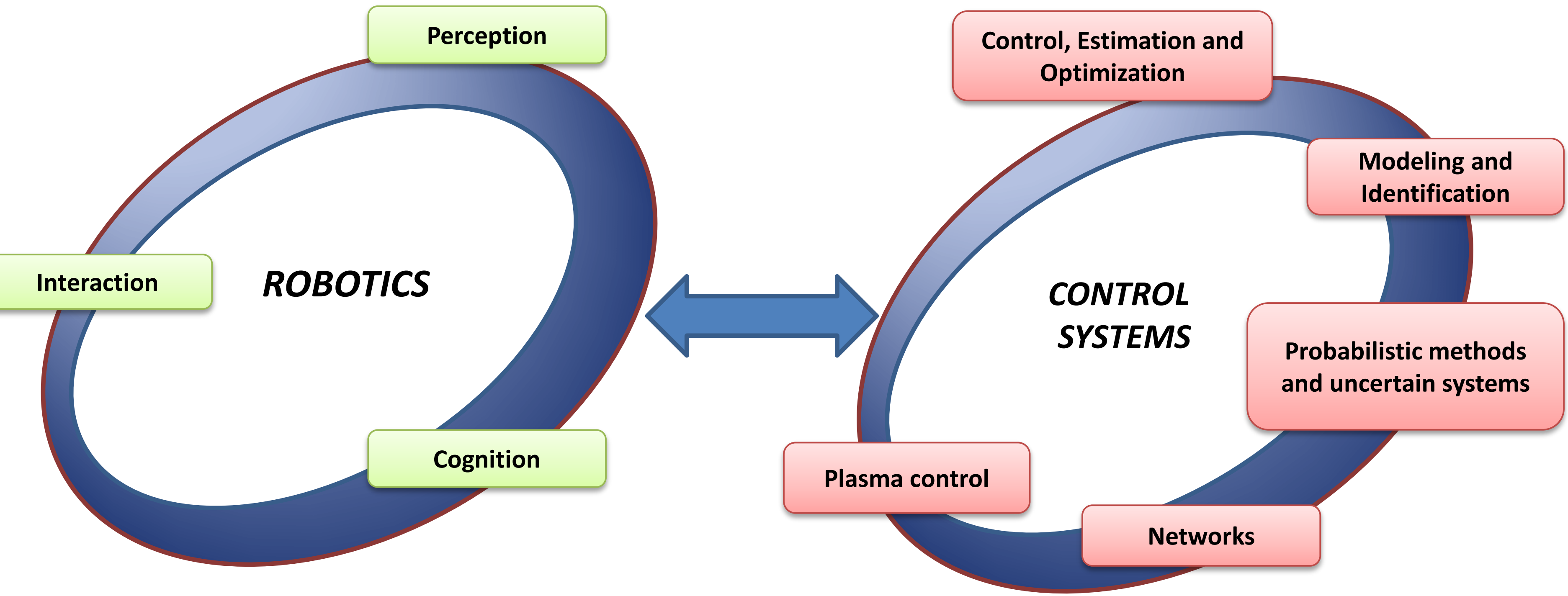

Perception ability

CNR CONTRIBUTION

- Development of advanced perception systems for ambient awareness of robotic platforms working in dynamic semi-structured and unstructured environments.
- Robust people perception (face expressions, sentiment and natural speech understanding, gesture recognition and classification)
- Design and development of novel estimation and cooperative perception strategies (including communication issues) for robotic networks, integrated with IoT devices, to perform tasks, such as cooperative mapping, cooperative manipulation, target tracking, and environmental monitoring.

IMPACT and CHALLENGES

- to enhance the autonomy and safety level of robotic platforms in dynamic environments
- to allow a robotic platform to effectively interact with humans sensing and interpreting people (emotions, motivations, desiderata) in real environments

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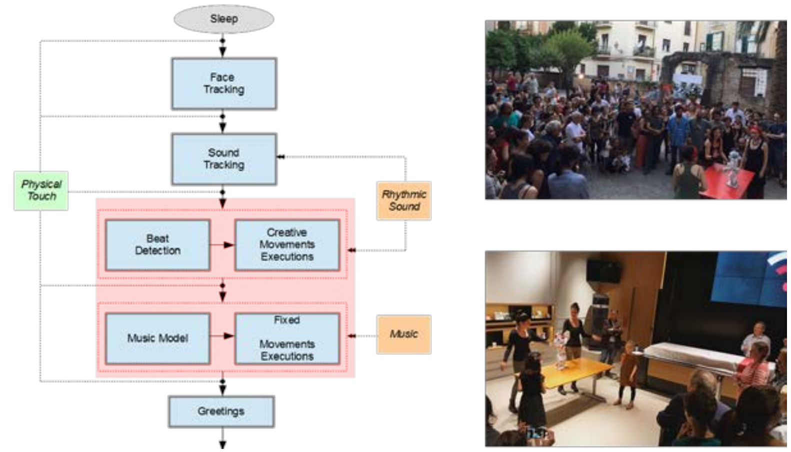
Roboceptions and robust sensing of human

CNR CONTRIBUTION

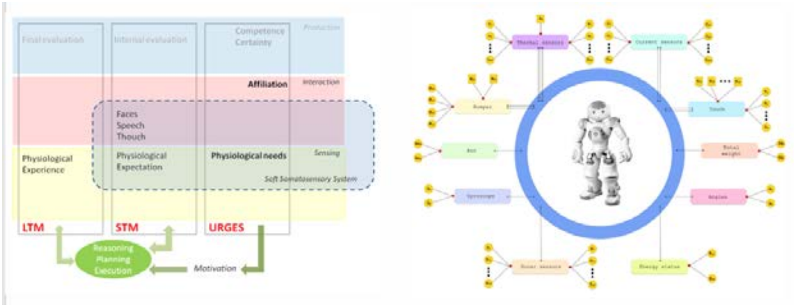
- People perception
  - Face expressions
  - Sentiment and natural speech understanding
  - Social signals (gesture recognition and classification)
- Environment perception
  - Building cognitive maps
  - Sound localisation and music detection and processing
- Internal sensing
  - Artificial Somatosensory System to model fatigue, discomfort, pleasure, and so on
- Robodanza video (perception phase)
  - http://www.pa.icar.cnr.it/scarlab/robodance/
- Artificial somatosensory system



People and environment sensing in complex real contexts

IMPACT and CHALLENGES

- Interpretation and sensing people (emotions, motivations, desiderata) in real environments
- Robot behaviour influenced by its mood and affective state to extabilish a strong relationship with human users



The artificial somatosensory system based on soft sensor approach

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Advanced sensing and perception technologies for autonomous vehicles

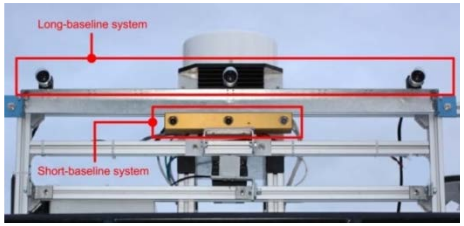
CNR CONTRIBUTION

- Multi-sensor platforms and multi-sensor processing algorithms, using alternative sensing techniques, for field applications
- Novel estimation and cooperative perception strategies for robotic networks, also integrated with IoT devices, with applications to cooperative mapping, target tracking, and environmental monitoring

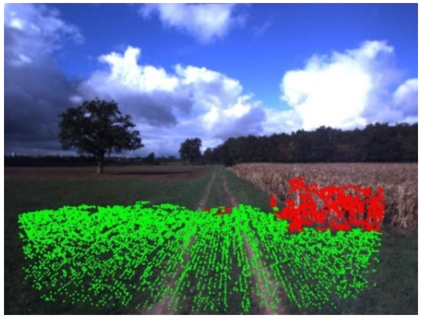
IMPACT and CHALLENGES

- enhancing the autonomy and safety level of robotic platforms operating in key sectors such as:
    - agriculture (i.e., development of highly automated vehicles and machines for precision farming applications)
    - manufacturing (i.e., process control, surveillance and security)
    - transport (i.e., autonomous vehicles and advanced driver-assistance systems)

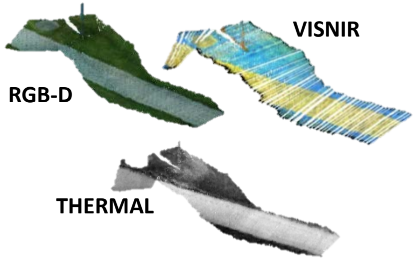
MULTI-SENSOR INTEGRATION



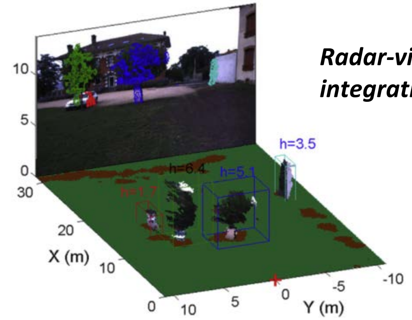
TRAVERSABILITY ASSESSMENT



MULTI-MODAL MAPPING

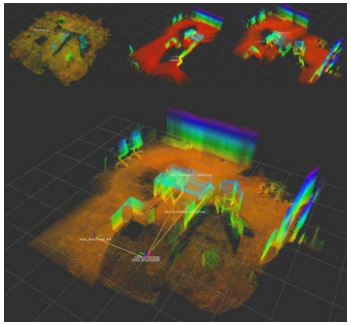


OBSTACLE DETECTION



Radar-vision integration

COOPERATIVE MAPPING



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Cognitive ability

CNR CONTRIBUTION

- design of suitable cognitive architectures inspired by human mind
- AI solutions for physical and cognitive interactions
- detection and recognition of human gestures, the processing of natural language, the knowledge representation by semantic and conceptual spaces

IMPACT AND CHALLENGES

- to extend the range of robotics application outside the typical context of the factory
- to develop a new model of representing human behaviors and managing complex interactions
- to improve the quality of the human life in a domestic environment
- to assure innovative health applications both in medical and home environments
- fruition of cultural heritage sites, and in general of public and commercial spaces
- to improve safety in the use of robotic systems in several critical environments, and in particular in all the human-robot collaborative operations

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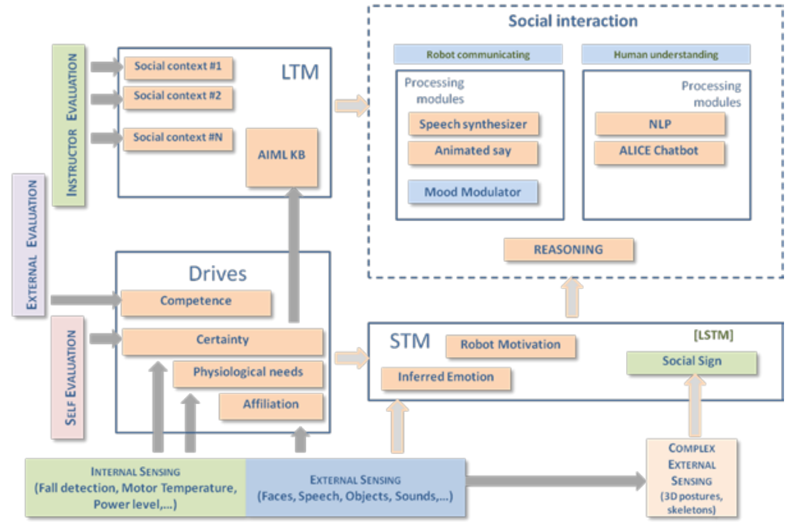
Developing Cognitive Architectures for Social Robots

CNR CONTRIBUTION

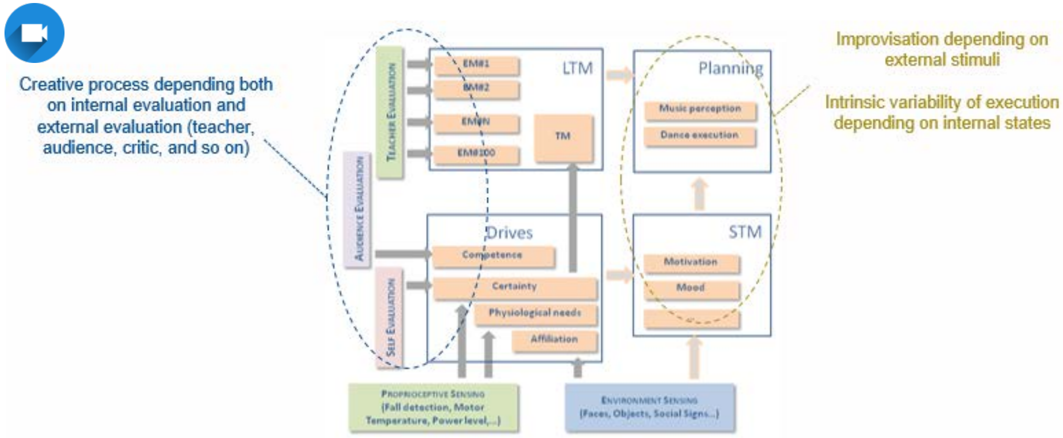
- Cognitive Architecture
  - Drives and demands
  - Emotions
  - Motivations
  - Learning by Imitation and demonstration
    - Interactive Genetic Algorithms
    - Artificial Neural Networks
    - Deep learning architectures
- Artificial Creativity
  - Internal and external evaluation loops
  - Improvisation capabilities
- Robodanza (improvisation and creative phase)



The robot Cognitive architecture for social interaction

IMPACT and CHALLENGES

- Exploiting cognitive capabilities to interact, collaborate with human in public, working and domestic context



The artificial creativity framework

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Interaction ability

CNR CONTRIBUTION

- soft-sensors approaches for data fusion, and machine learning methodologies to process the knowledge (e.g., interactive genetic algorithms, artificial neural networks, deep learning architectures).
- collaborative robot control paradigms, providing a constant and dynamic information flow between the operator and the robot to increase safety

IMPACT AND CHALLENGES

- to assure complex and natural human-robot interactions for collaborative tasks and social supports
- a new social role of robots taking into account different aspects such as wellbeing, safety, health, and productivity
- to make the presence of the robot acceptable and useful for human purposes in real scenarios (i.e., workplaces, houses, hospitals, schools, shops, museums)

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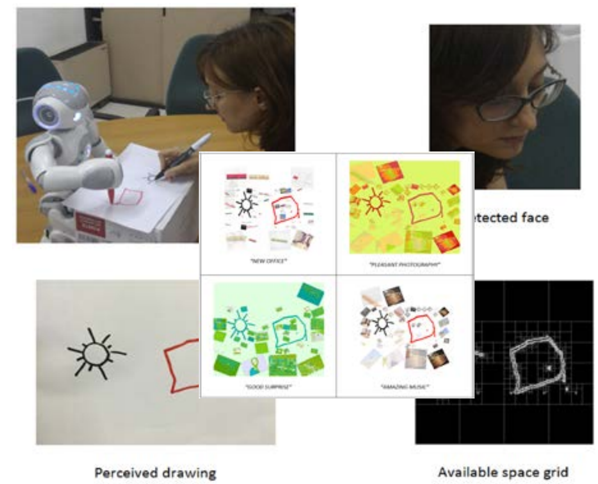
Human-robot social interaction based on emotion and motivation

CNR CONTRIBUTION

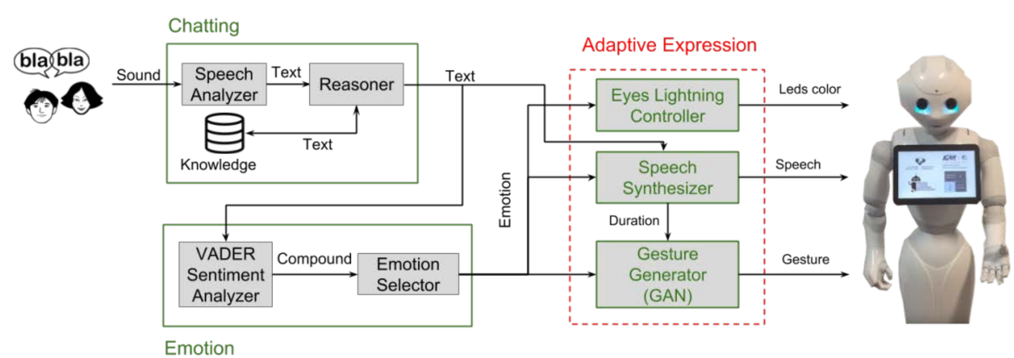
- Social Interactions based on social practices
  - Social role definitions
  - Dynamic change of roles and behaviors
  - Adaptability to the user and social context
- Natural Human-Robot Interaction
  - Imitation of human gestures and speech parameters
  - Emotive/affective interactions
  - Sharing knowledge and experience by bioinspired mechanisms
- Video Demo at Farnesina
- Video Robodanza



Interaction/collaboration by sharing knowledge and activity representation to create artworks

IMPACT and CHALLENGES

- Managing complex human-robot interaction, exstabilishing long-term social support based on affective envolvement



Combining speech, gestures and emotion based signals to show a realistic robot behavior during interaction

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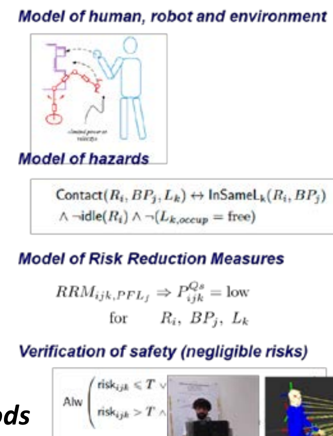
Human-robot collaboration

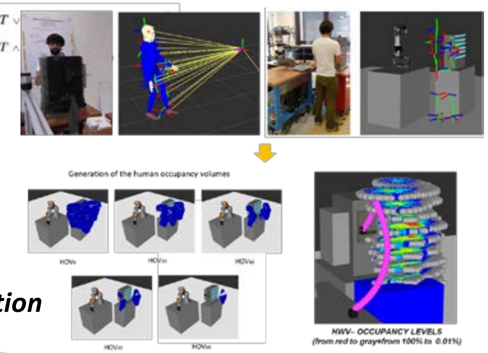
CNR CONTRIBUTION

- Safety: architecture, speed and separation monitoring, power and force limitation
- Semi-automated model-based risk assessment
- Evalaution of human comfort and perceived safety
- Human tracking for occupancy estimation
- Estimation of the robot execution time in HRC
- Off-line motion planning and real-time scheduling
- Real-time motion planning and scheduling



Safety verification: formal methods (Linear Temporal Logic) + model checking for automatic hazard identification, human error and unintended uses, risk estimation

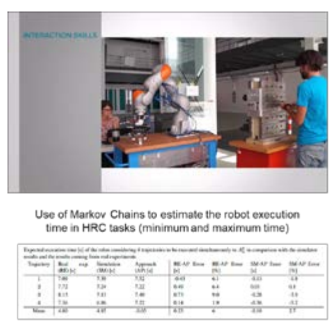
Worker Empowerment

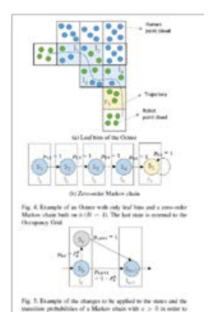


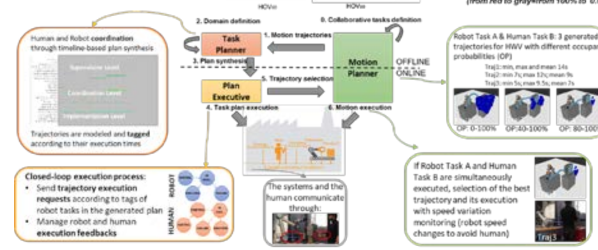
Human tracking for occupancy estimation

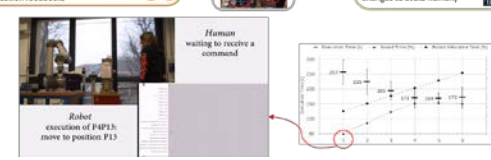
IMPACT and CHALLENGES

- Managing productive human-robot collaboration in advanced manufacturing scenario









Estimation of the robot execution time in HRC; Off-line motion planning and real-time scheduling; Real-time motion planning and scheduling

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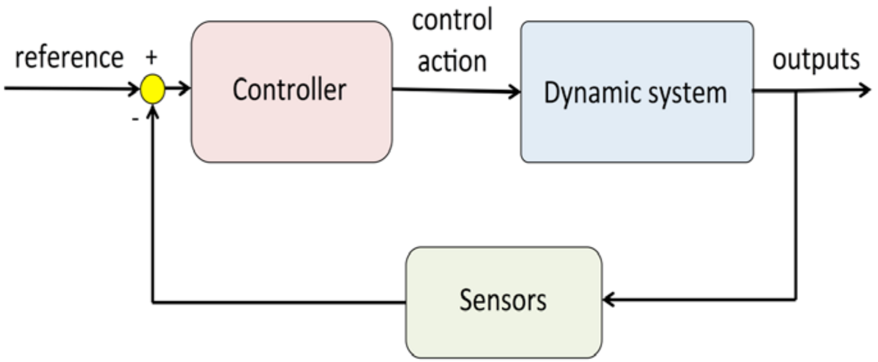
Control, estimation and optimization

CNR CONTRIBUTION

- Model predictive control.
- Approximate dynamic programming.
- Observer design.
- Nonlinear filtering.
- Moving horizon estimation.
- Functional optimization.
- Neural networks.
- Consensus.
- Robust control.
- Sliding mode.
- Distributed control and estimation.

IMPACT AND CHALLENGES

- Control, state estimation, and optimization for complex nonlinear systems are fundamental for increasing efficiency.



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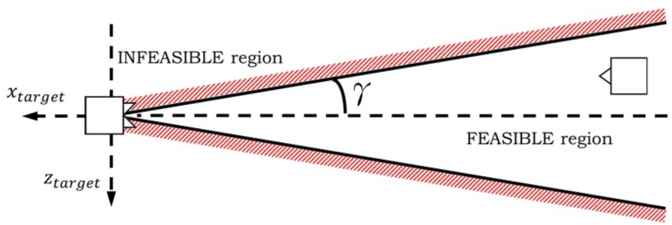
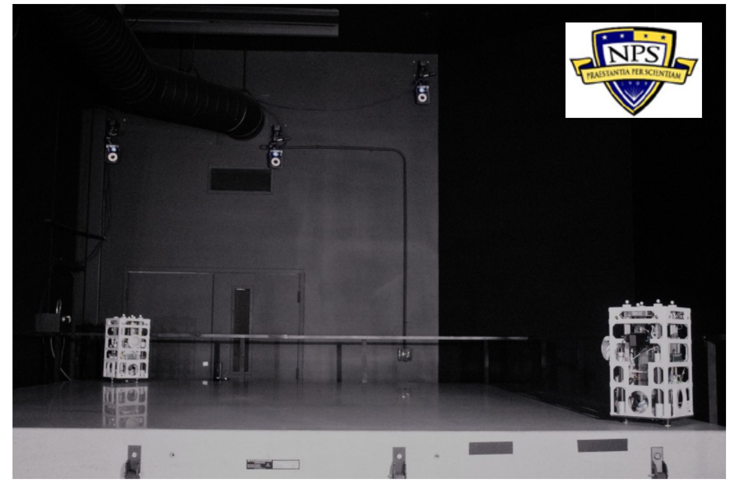
Rendezvous and Docking (RV&D) Maneuvers of Spacecraft

CNR CONTRIBUTION

- Modern control strategies (Sliding Mode and Stochastic MPC) for automatic RV&D of spacecraft

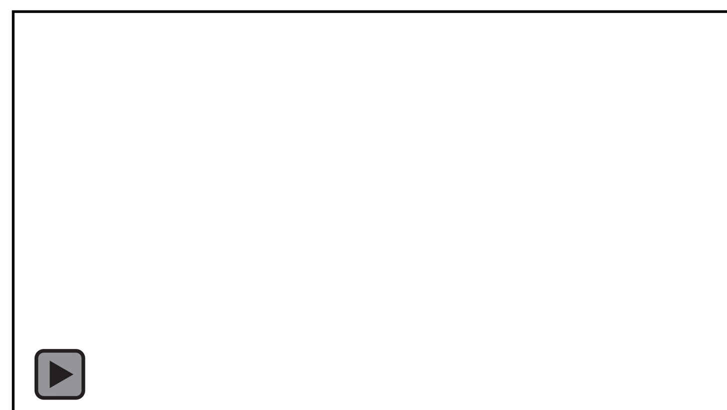


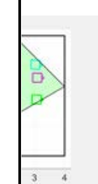


NPS-POSEIDYN testbed, with Vicon motion capture, FSSs, and granite monolith at the Spacecraft Robotics Lab., NPS The target FSS is on the right and the chaser on the left.

IMPACT AND CHALLENGES

- Allow automated RV&D in the presence of noise and uncertainty
- Reduction of energy consumption, obstacle avoidance





Experimental results

E Capello, E Punta, F Dabbene, G Guglieri, R Tempo, "Sliding-mode control strategies for rendezvous and docking maneuvers," Journal of Guidance, Control, and Dynamics 40 (6), 1481-1487

M Mammarella, E Capello, M Lorenzen, F Dabbene, F Allgower , " A general sampling-based SMPC approach to spacecraft proximity operations ," IEEE Conf. on Decision and Control (CDC), 2017, 4521-4526

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Moving-horizon estimation for nonlinear systems

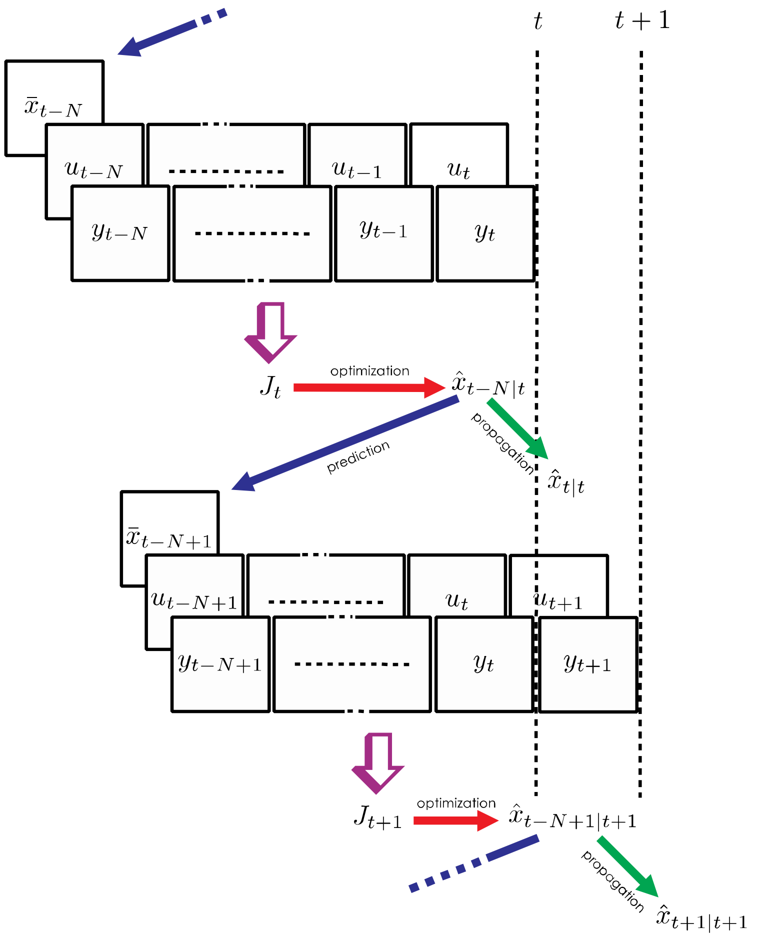
CNR CONTRIBUTION

- Fast moving-horizon estimation (MHE) for discrete-time linear and nonlinear systems based on only one descent iteration:
  - gradient-based MHE;
  - Newton-based MHE;
  - Conjugate-gradient-based MHE.
- Stability properties of the approximation error can be proved.

IMPACT AND CHALLENGES

- Good tradeoff between estimation accuracy and computational effort.
- Better results than traditional methods for estimation, such as the Extended Kalman Filter.

A. Alessandri, M. Gaggero, "Fast moving horizon state estimation for discrete-time systems using single and multi iteration descent methods", IEEE Transactions on Automatic Control, vol. 62, no. 9, pp. 4499-4511, 2017.



Optimization, prediction an propagation steps of the moving-horizon approach.

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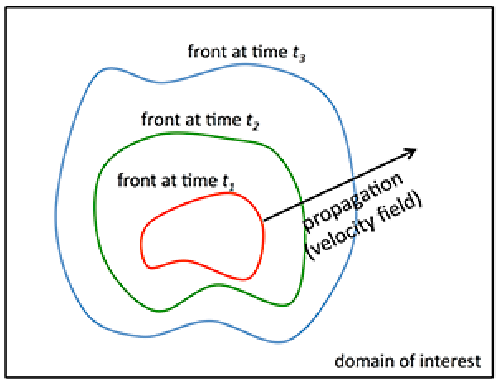
Optimal control of level set methods

CNR CONTRIBUTION

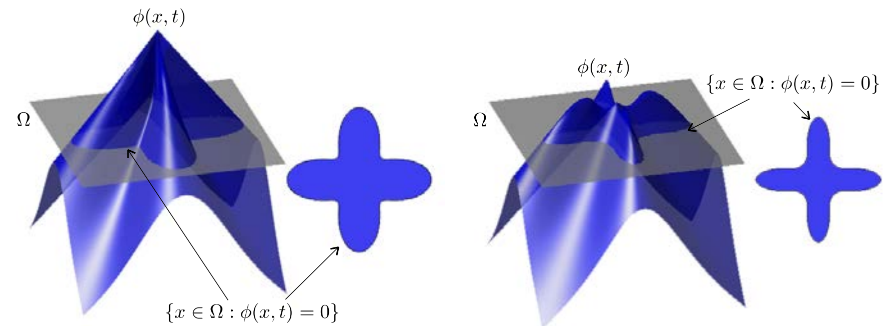
- New approach for identification and optimal control of propagating fronts or interfaces existing in the real world.



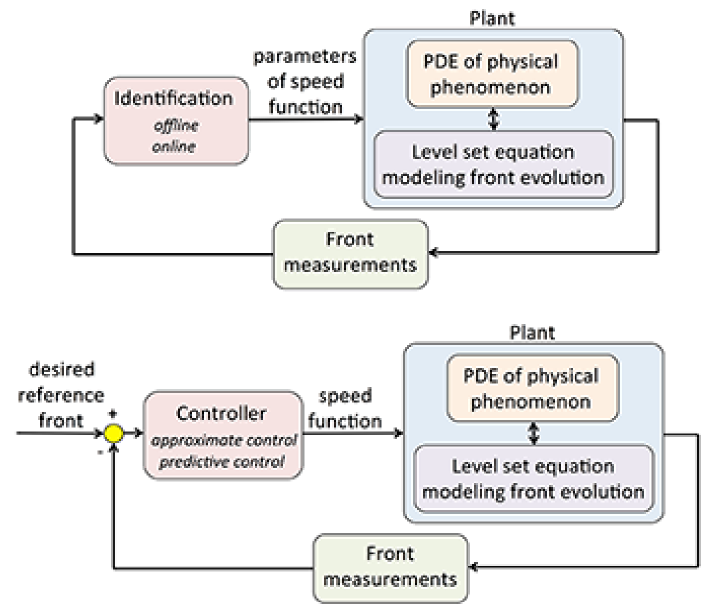
IMPACT AND CHALLENGES

- A challenging mathematical framework relevant in cross-disciplinary fields is developed, with focus on identification and control in the light of front propagation using level set methods.

A. Alessandri, P. Bagnerini, M. Gaggero, "Optimal control of propagating fronts by using level set methods and neural approximations", IEEE Transactions on Neural Networks and Learning Systems, 2018.



In level set methods, the front is represented as the zero level set of a higher-dimensional function



Block schemes of the proposed approach for identification and control

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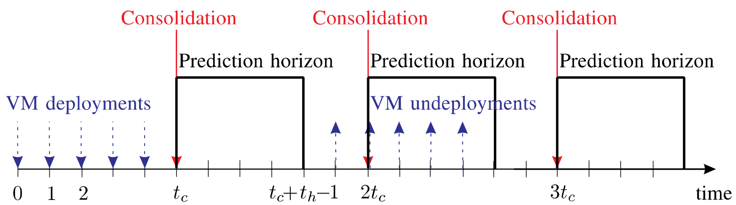
Energy-aware consolidation and placement of virtual machines

CNR CONTRIBUTION

- Placement and consolidation strategies to migrate and deploy virtual machines over servers.
- Model predictive control to exploit future information together with efficient, online optimization techniques.

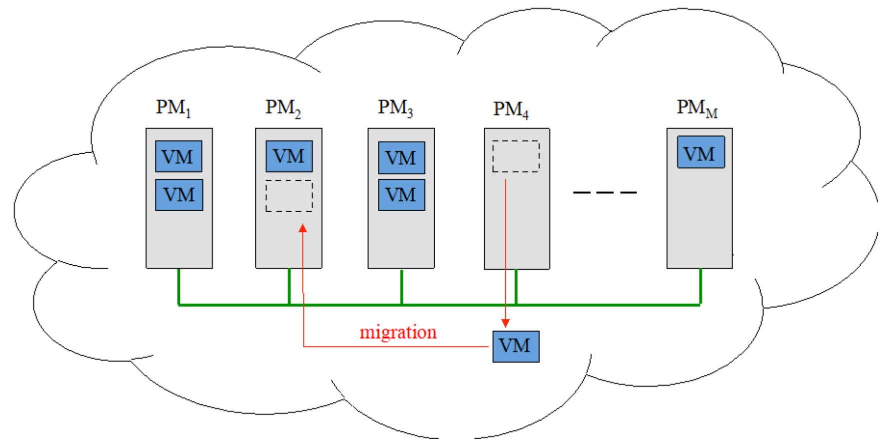


IMPACT AND CHALLENGES

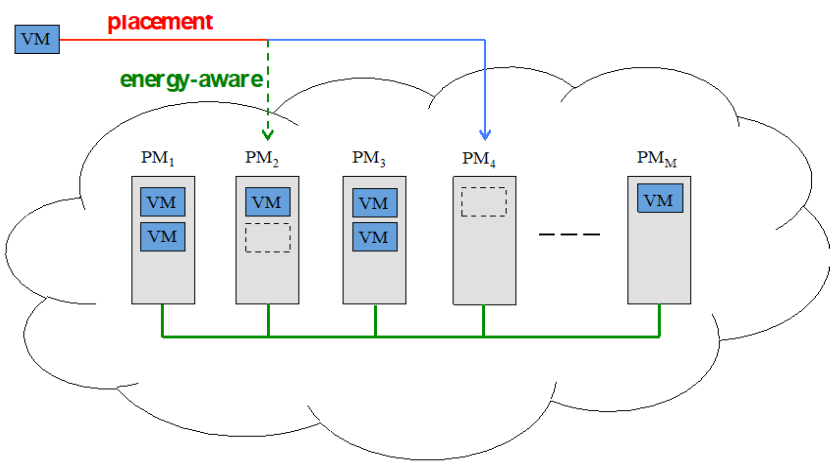
- Reduce the energy consumption of Internet-scale datacenters while maintain suitable degree of quality, security, and dependability.

M. Gaggero, L. Caviglione, "Predictive control for energy-aware consolidation in cloud datacenters", IEEE Transactions on Control Systems Technology, vol. 24, no. 2, pp. 461-474, 2016.

M. Gaggero, L. Caviglione, "Model predictive control for energy-efficient, quality-aware, and secure virtual machine placement", IEEE Transactions on Automation Science and Engineering, 2018.



VM is migrated to offload the server, which can be put in sleep to save energy



The requested VM initially placed in order to avoid overloading the servers and to save energy

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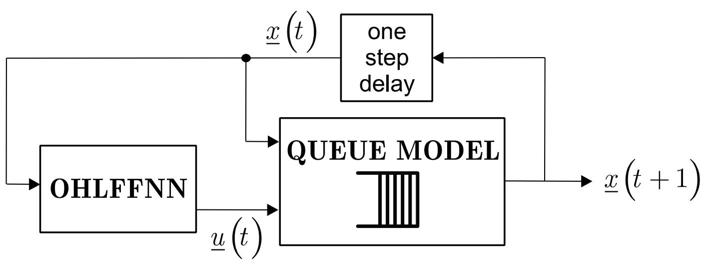
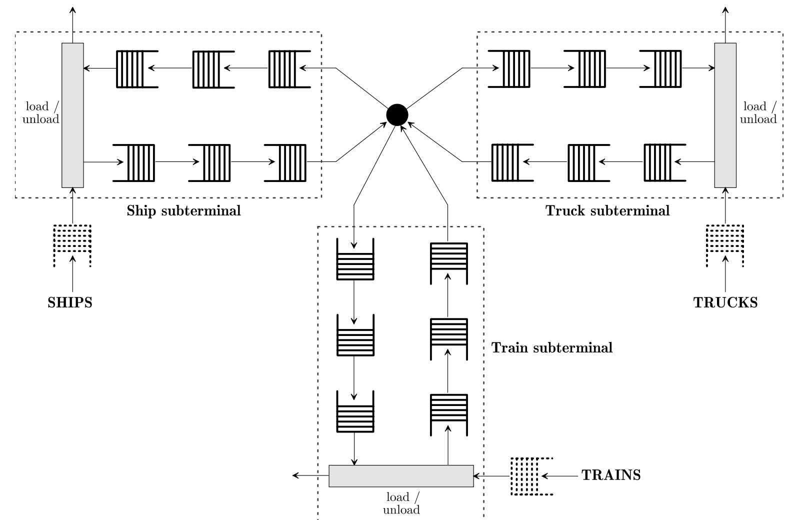
Predictive control for resource allocation in container terminals

CNR CONTRIBUTION

- Efficient allocation of resources moving containers in intermodal terminals.
- Use of model predictive control to exploit predictions on future events.
- Neural networks to approximate the dynamics and optimal control actions and reduce computational effort.

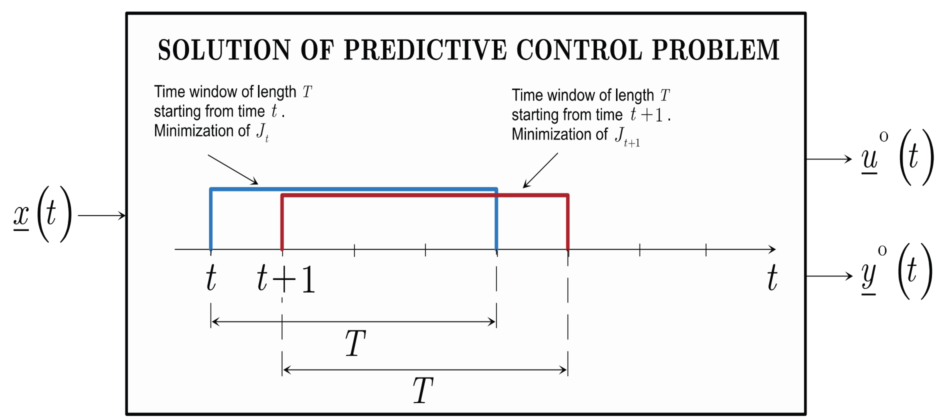




Queue model of a container terminal

IMPACT AND CHALLENGES

- Reduce the lay times of carriers and hence increase the throughput of the terminal.



Scheme of the predictive control approach

A. Alessandri, C. Cervellera, M. Gaggero, "Predictive control of container flows in maritime intermodal terminals", IEEE Transactions on Control Systems Technology, vol. 21, no. 4, pp. 1423-1431, 2013.

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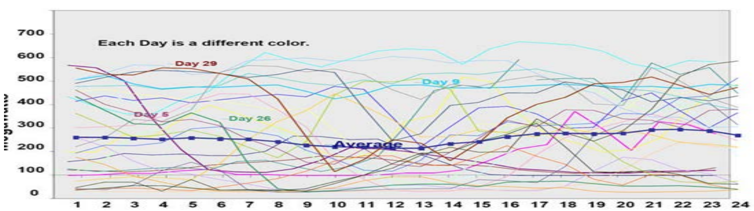
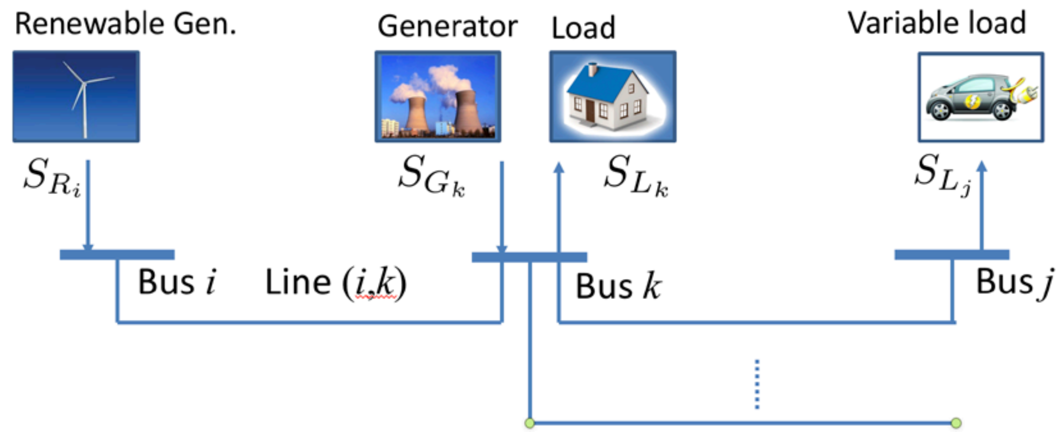
Optimal power flow in the presence of Renewable Energies

CNR CONTRIBUTION

- Sample-based optimal power flow design, able to take into account fluctuations due to high variability of renewable generation



Hourly variation of energy production in Tehachapi Wind Farm,Southern CA

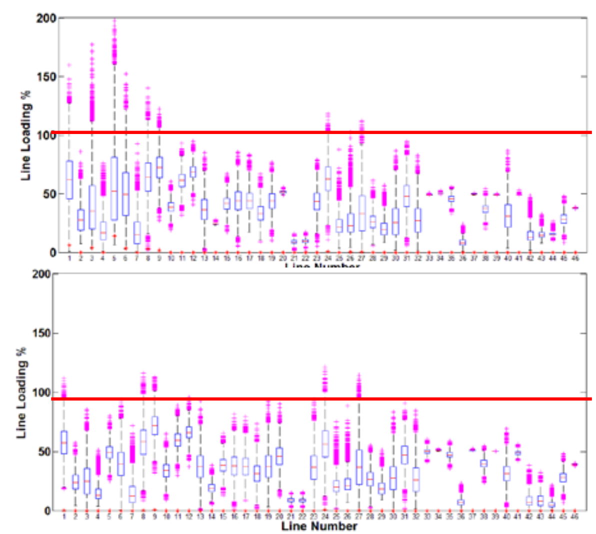


Power grid with high penetration of renewable energy

IMPACT AND CHALLENGES

- Minimization of line violations
- Optimization of cost generation

Joint International Lab COOPS (Cooperative Control for Energy Management Systems CNR and Japan Science and Technology Agency (JST), Osaka University



Line violation with nominal OPF design (top) and sample-based robust OPF (bottom)

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Mathematical Control and Information Theory

CNR CONTRIBUTION

- Structural properties of nonlinear systems described by Ordinary Differential Equations (ODE)
- Solution calculation for nonlinear ODEs by analytic means
- Stochastic Systems described by Stochastic Differential Equations (SDE)
- Efficient solution of inference problems for Hidden Reciprocal Processes (HRP)

IMPACT and CHALLENGES

Obtained results:

- Reduction of nonlinearity to a simpler quadratic case (Exact Quadratization).
- A simpler controllability test for nonlinear systems.
- Exact Moments Equation (infinite dimensionale) for nonlinear SDEs
- Representation of natural speech as an HRP, with Consequent efficient solution for the Inference problem.

Challenges: ‘Model based’ control algorithms Automatic ‘understanding’ of natural languages.

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Modeling and identification

CNR CONTRIBUTION

- Parametric identification.
- Black-box modeling.
- Study of the structural properties and solutions of differential systems.
- Positive systems.
- Fault diagnosis.
- Interconnected and distributed systems.
- Multi-agent systems.
- Model building starting from statistical descriptions.
- Systems of systems.

IMPACT AND CHALLENGES

- Systems modeling and identification play a fundamental role in the design of control systems.
- Having at disposal an accurate model of a process makes it possible to design effective control techniques that exploit future information and also prevent possible failures.
- Often, the models are built starting from a few data collected on the field that are affected by disturbances.

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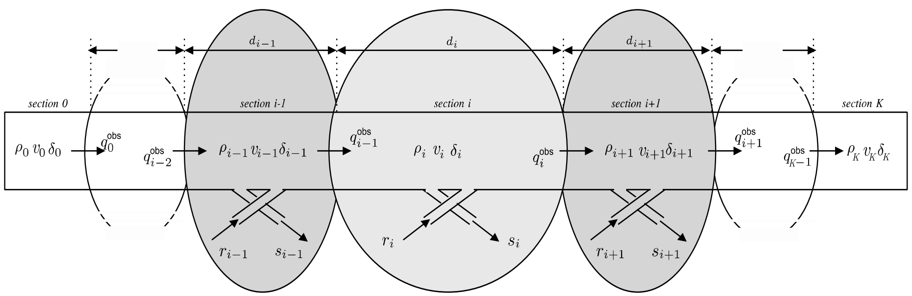
White-box and black-box parameter identification of freeway traffic

CNR CONTRIBUTION

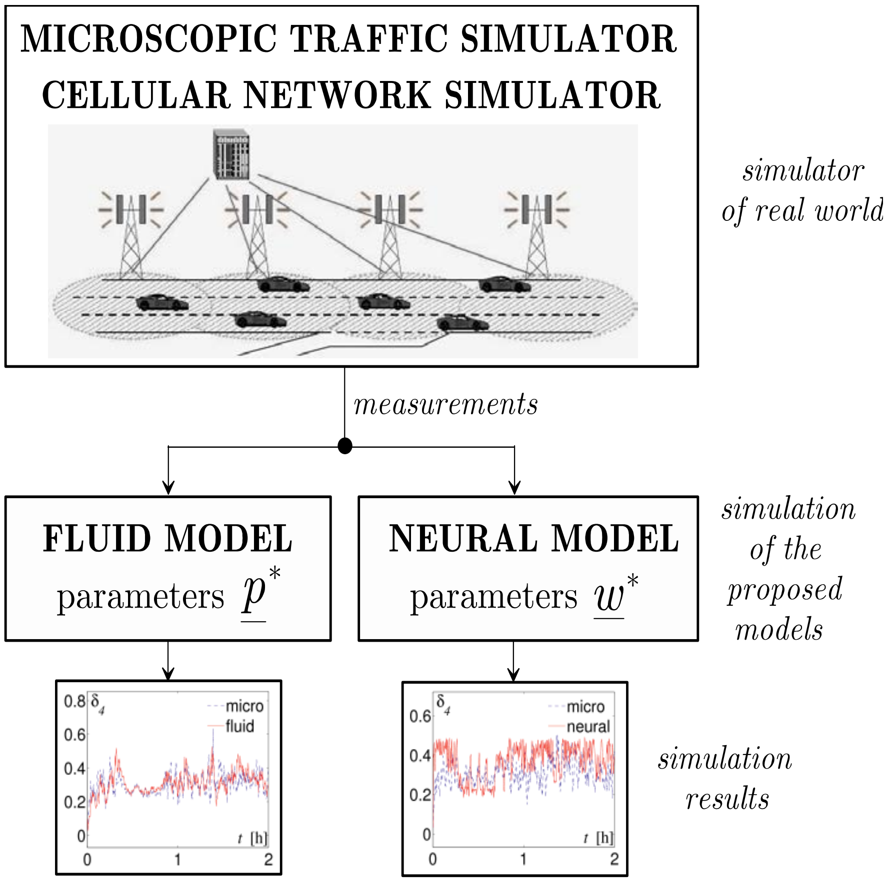
- Dynamic models to describe traffic on a freeway based on the information provided by a wireless cellular network.
- Two different approaches: 1) extension to macroscopic traffic models and 2) use a neural network to approximate the dynamics of traffic.



IMPACT AND CHALLENGES

- Both approaches require the identification of the corresponding parameters, i.e., the parameters of the macroscopic model and the neural weights for the latter.

A. Alessandri, R. Bolla, M. Gaggero, M. Repetto, "Modeling and identification of nonlinear dynamics for freeway traffic by using information from a mobile cellular network", IEEE Transactions on Control Systems Technology, vol. 17, no. 4, pp. 952-959, 2009



Block diagram of the overall approach

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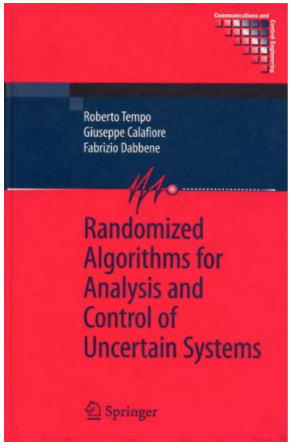
Probabilistic methods and uncertain systems

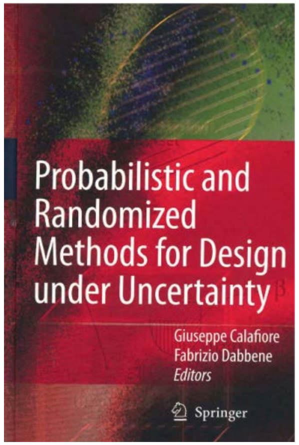
CNR CONTRIBUTION

- The starting point is the assumption that uncertainty is described in a stochastic manner, and the goal is to provide probabilistic assessments of system performance.
- We accept the risk that a certain property of the system is violated with low probability.
- Such systems can be seen as "practically robust" from a technological point of view.

IMPACT AND CHALLENGES

- Provide a link between stochastic and robust methods, using innovative concepts such as the probabilistic robustness margin and the probability degradation function.





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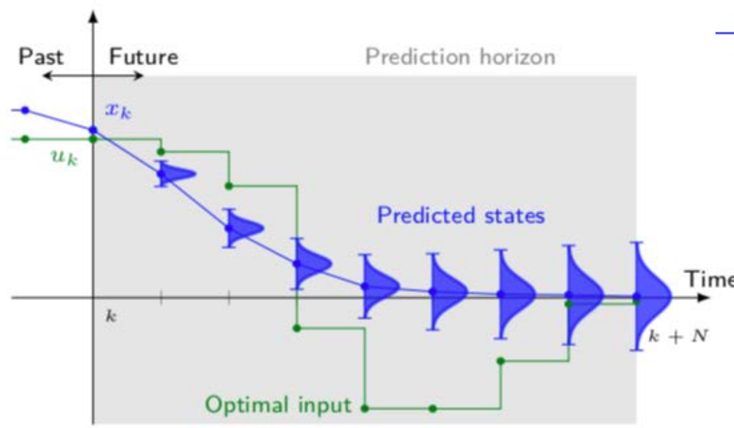
Sample-based Model Predictive Control

CNR CONTRIBUTION

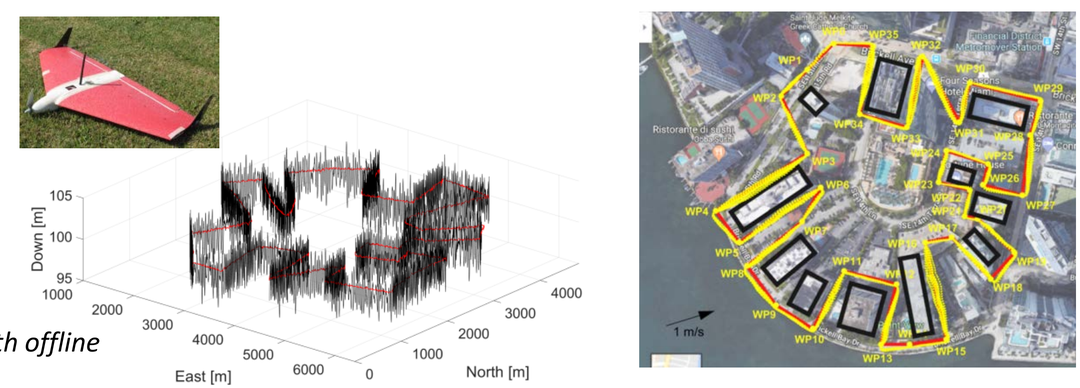
- Definition of an offline sampling scheme for the design of robust model predictive control schemes.
- Fast MPC algorithm, able to cope with noise and uncertainty.
- Different applications, ranging from UAVs to power systems



Stochastic model predictive control

IMPACT AND CHALLENGES

- Fast and implementable SMPC schemes



Experimental results of Sample-based SMPC for UAV tracking in Miami area

M Lorenzen, F Dabbene, R Tempo, F Allgöwer, «Stochastic MPC with offline uncertainty sampling,» Automatica, 2017.
M Lorenzen, F Dabbene, R Tempo, F Allgöwer, «Constraint-tightening and stability in stochastic model predictive control,» IEEE Trans. on Automatic Control, 2017.
M Mammarella, E Capello, F Dabbene, G Guglieri, «Sample-based SMPC for tracking control of fixed-wing UAV, IEEE Control Systems Letters, 2018.

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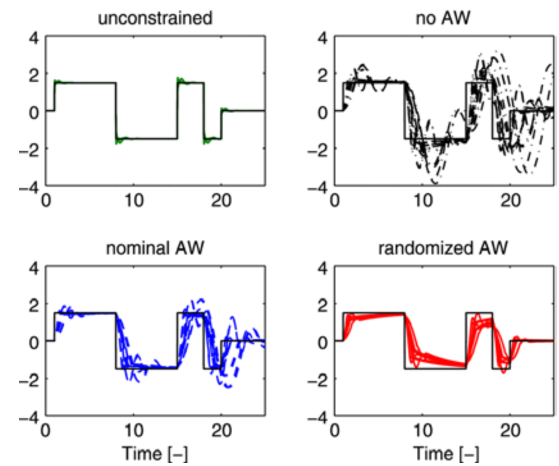
Randomized anti-windup schemes

CNR CONTRIBUTION

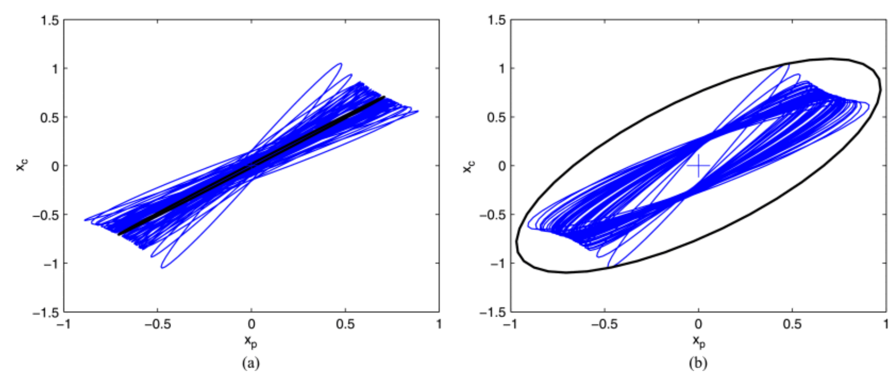
- An anti-windup scheme able to cope with noise and uncertainty
- Design based on a combination of convex-optimization and randomized algorithms

IMPACT AND CHALLENGES

- Dealing in an efficient way with problems of input saturation in the presence of various sorces of uncertainty



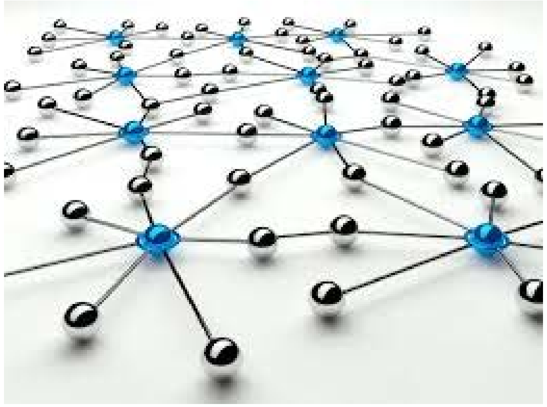
Robust anti-windup response compared to nominal one



Experimental results of Sample-based SMPC for UAV tracking in Miami area

S Formentin, F Dabbene, R Tempo, L Zaccarian, SM Savaresi, «Robust linear static anti-windup with probabilistic certificates,» IEEE Transactions on Automatic Control, 2017

Network Analysis and Control



CNR CONTRIBUTION

- Crucial research in consensus the coordination of multi-agent systems through a graph-based approach.
- Significant results in contexts such as social networks, synchronization of wireless sensor networks, development of robotic networks using distributed algorithms, and control systems over non-ideal communication networks.

IMPACT AND CHALLENGES

- Networks represent a research activity that includes several applications of interest, such as the rapid spread of financial crises and epidemics, the aggregation of human behavior, and the development of the Internet.

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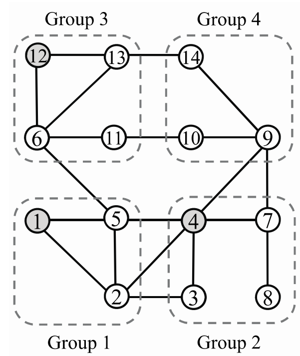
Distributed estimation and optimization in multi-agent systems

CNR CONTRIBUTION

- Processing and estimation when the observed data are acquired in a network avoiding the use of a central processing unit and long-range communications.
- Significant results in contexts of synchronization, localization in wireless sensor networks, parameter estimation for monitoring and event detection, power systems estimation.



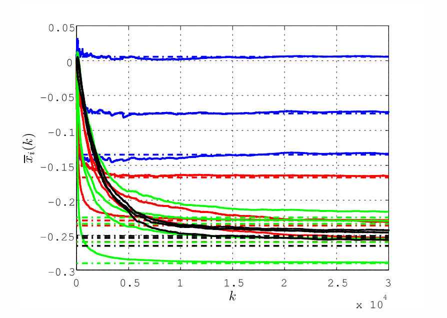


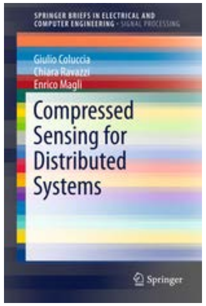
Figure 6: Time responses of the time-average states (in solid lines)

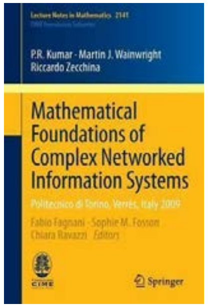
Distributed algorithm based on grouping for power system estimation

IMPACT AND CHALLENGES

- In-network randomized algorithms working with limited amount of information, low-complexity requirements, performing under communication constraints

C. Ravazzi, S. M. Fosson, E. Magli, «Randomized algorithms for distributed nonlinear optimization under sparsity constraints», IEEE Transactions on Signal Processing, 2016
C. Ravazzi, P. Frasca, R. Tempo, H. Ishii, «Ergodic Randomized Algorithms and Dynamics over Networks, IEEE Transactions on Control of Network Systems», 2015.
C. Ravazzi, S. M. Fosson, E. Magli, «Distributed iterative thresholding for l_0/l_1-regularized linear inverse problems», IEEE Transactions on Information Theory, 2015
F. Fagnani, S. M. Fosson, C. Ravazzi, «A distributed classification/estimation algorithm for sensor networks», SIAM Journal on Control and Optimization, 2014





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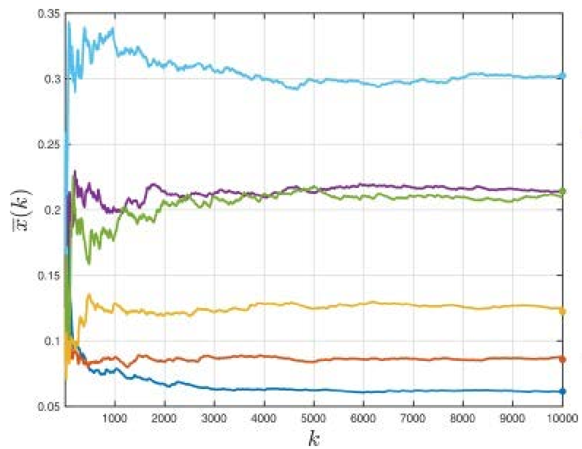
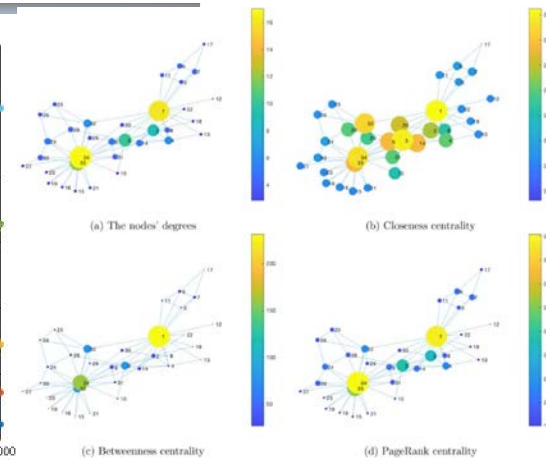
Social networks inference and analysis



a



b

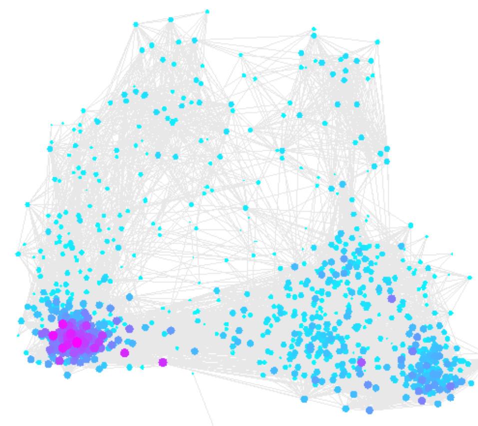
a) Evolution of average opinion in gossip based networks and
b) Depiction of different centrality measures

CNR CONTRIBUTION

- Study of dynamics of social networks and belief systems
- Distributed algorithms for their exploration

IMPACT AND CHALLENGES

- Definition of gossip-based dynamics over networks
- Study of entangled and multidimensional models



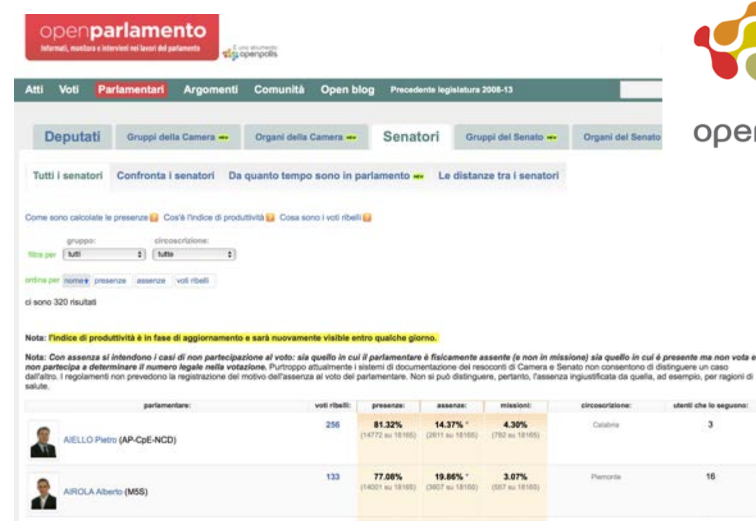
Reconstruction of Facebook Ego network from opinion evolution measurements

C Ravazzi, R Tempo, F Dabbene, «Learning influence structure in sparse social networks,» IEEE Transactions on Control of Network Systems, 2018
AV Proskurnikov, C Ravazzi, F Dabbene, «Dynamics and structure of social networks from a systems and control viewpoint: A survey of Roberto Tempo's contributions,» Online Social Networks and Media, 2018
NE Friedkin, AV Proskurnikov, R Tempo, SE Parsegov"Network science on belief system dynamics under logic constraints" Science, 354, 321-326, 2016

Analysis of relationships in Italian Parliament

CNR CONTRIBUTION

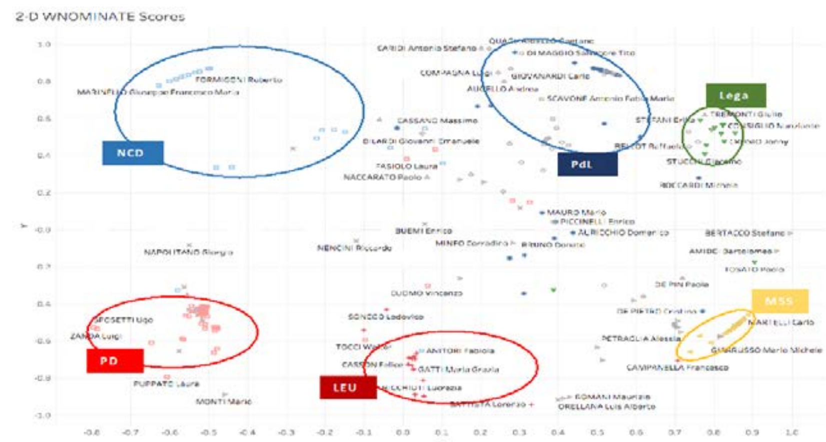
- Analysis of the political orientation and reconstruction of the influence network of Italian Parliament



Openparlamento site, collecting historical data of Senate votes

IMPACT AND CHALLENGES

- Classification of the political orientation of the Senators based exclusively on the roll call data.
- Automatic outliers detection and prediction
- Analysis of leadership of different groups, e.g. parties, members, genders, etc.



Automatic data-driven assessment of political orientation of the Senators of the XVII Legislature

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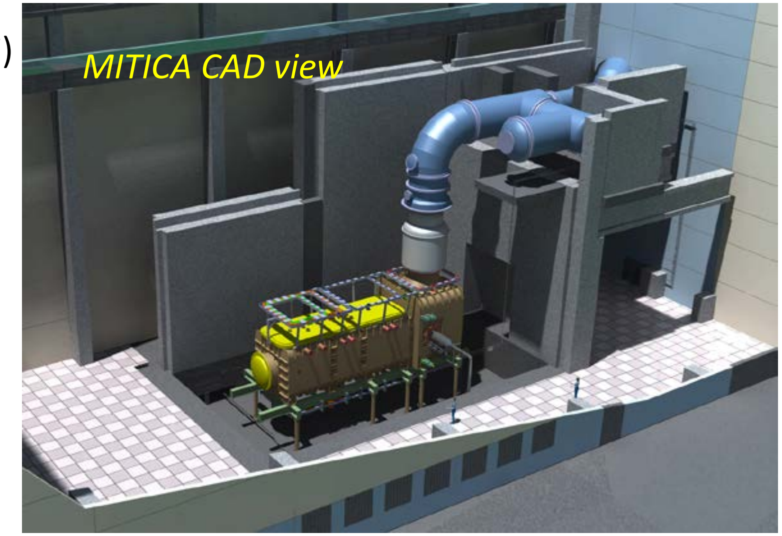
Neutral Beam Test Facility (NBTF) – Control

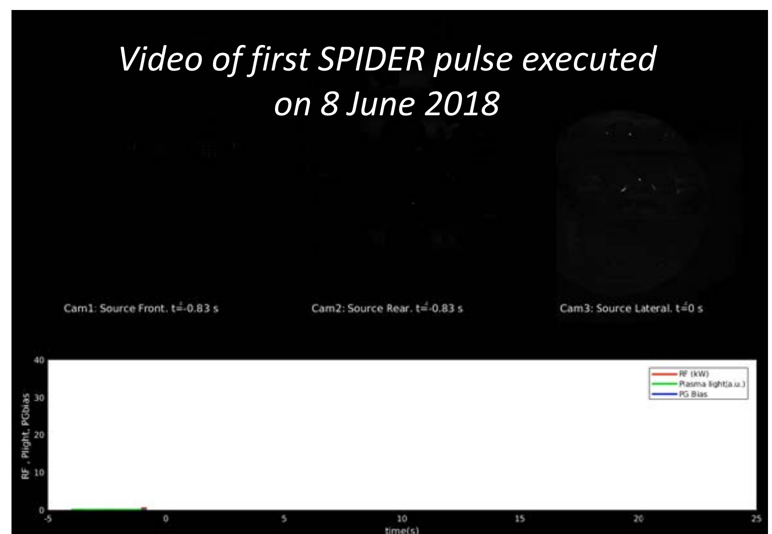
CNR CONTRIBUTION

- Realization of the ITER Neutral Beam Test Facility (NBTF)
- Instrumentation and Control System
- IGI - Consorzio RFX



IMPACT and CHALLENGES

- Control in fusion Neutral Beam Injectors plays a fundamental role in demonstrating the technological feasibility of high-energy, high-power Neutral Beam Injectors.
- SPIDER, the largest ion source in the world, has started operation under central control in June 2018.
- Future challenge is to contribute to the demonstration of feasibility of MITICA, the full-size ITER Neutral Beam Injector Prototype under construction in Padova.



NBTF – SPIDER Control

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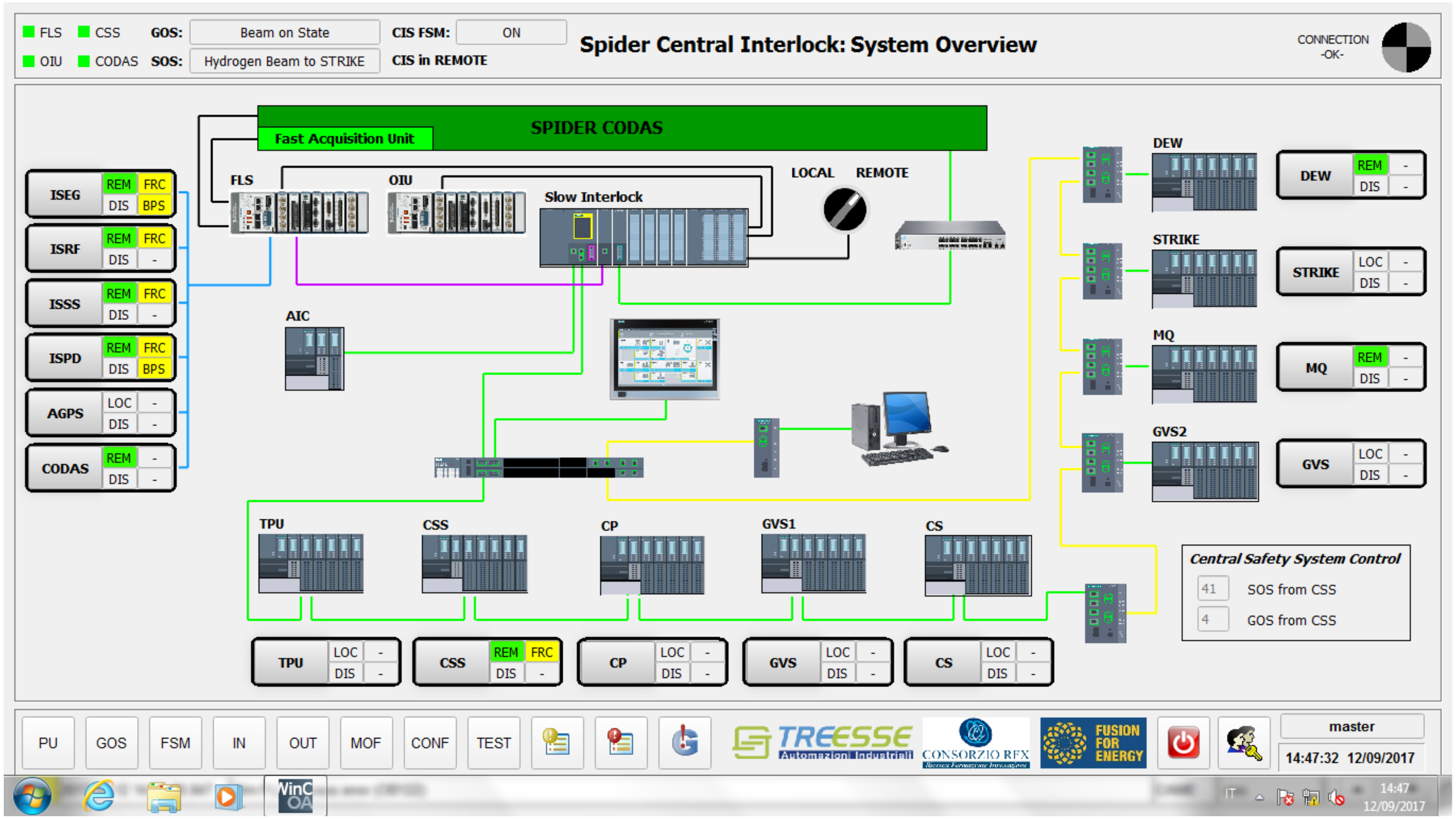
Machine Investment Protection (Central Interlock System)



HMI overview of SPIDER Central Interlock System

IMPACT and CHALLENGES

Distributed system to provide investment protection - IEC61508 Safety Integrity level 2

Reaction time for fast protection functions: 10 µs

Reaction time for slow protection functions: 20 ms

FPGA + PLC + SCADA integration – Data-driven software approach

NBTF – SPIDER Diagnostics Data Acquisition

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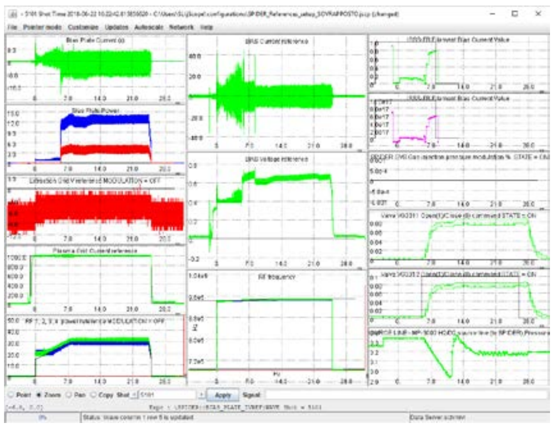
CNR CONTRIBUTION

- Realization of the ITER Neutral Beam Test Facility
- Instrumentation and Control System
- IGI - Consorzio RFX



Summary plot

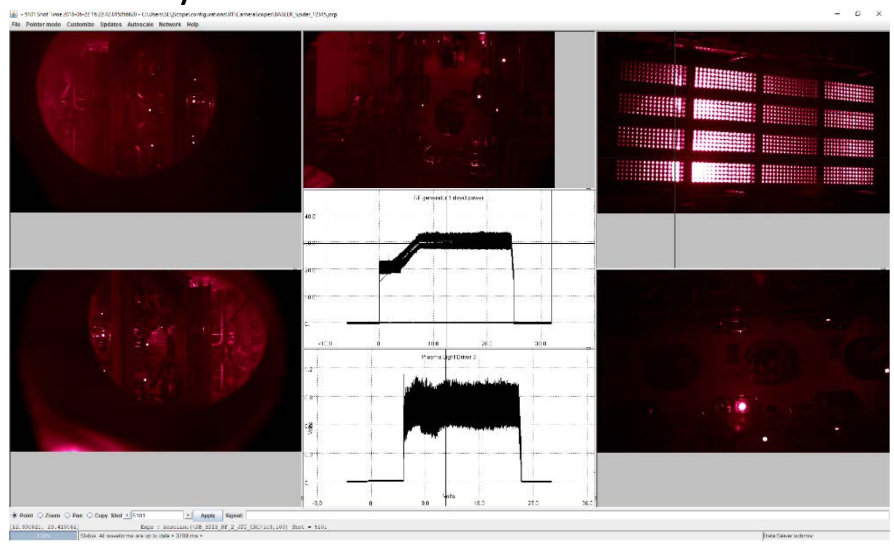


Image data acquisition

IMPACT and CHALLENGES

- SPIDER Diagnostics Data Acquisition allows an in-depth insight into the beam physics and represents a key feature to understand the beam phenomena.
- The real-time implementation of diagnostics data is challenging due to system complexity (signal number and processing) associated with a low latency requirement .
- Real-time diagnostics information may be used for feedback and feed forward control of beam parameters.
- Examples of diagnostics data acquisition are presented hereafter in the next slides

NBTF – SPIDER Diagnostics Data Acquisition

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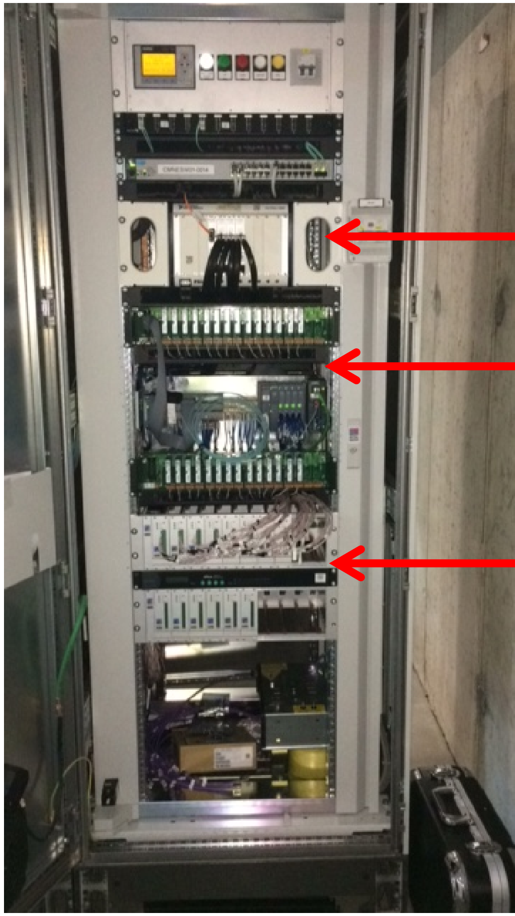
Thermal Measurements



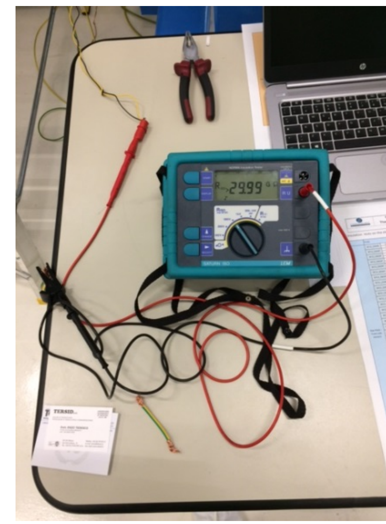
Data Acquisition Unit

Thermal Protection Unit

Custom electronics: calorimetry

Surface masurements

HV Insulation tests



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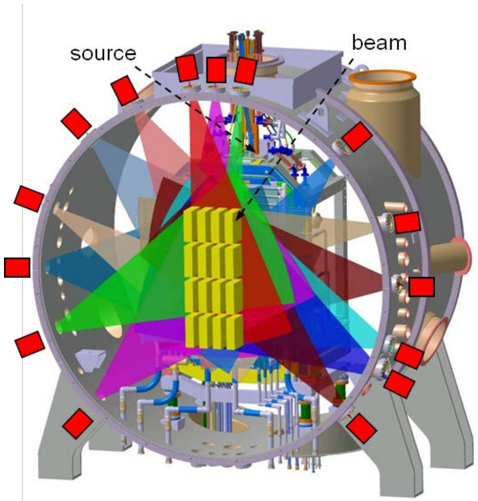
2D Beam Tomography

Camera	Basler CMOS camera	Custom linear camera
sensor	CMOS Sony Pregius IMX-249 1920 x 1200pix 5.86 µm	CMOS Hamamatsu S11639-01 2048 pix 14x200 µm
Dynamic range	12 bit, 72 dB	5000:1
Max frame rate	40 Hz	4 kHz
Interface	GigE POE	3 dig, 1 video
Power	3 W	low
Rad. hardness	complex electronics	simple electronics

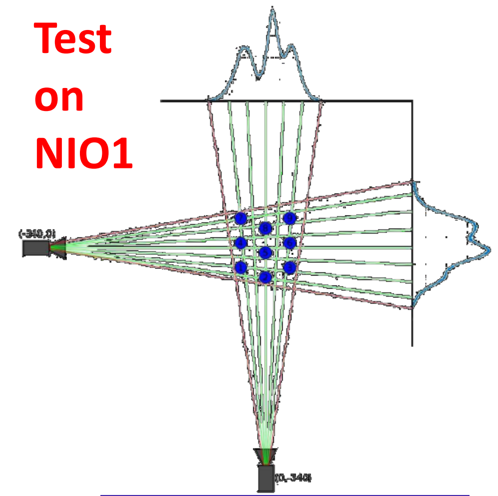


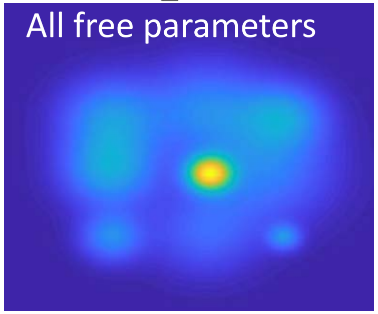
Essential black background

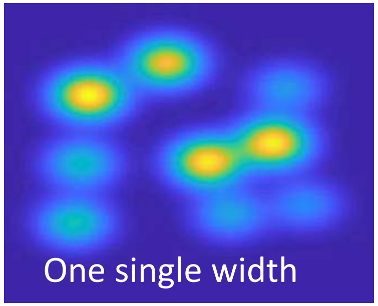
- Continue test on NIO1:
- Develop tomographic algorithm
- Preliminary 2 cameras Tomo
- Next: 3 cameras Tomo

It is time to investigate real time analysis, for on line monitoring and possible feedback

Test on NIO1







NBTF – SPIDER Diagnostics Data Acquisition

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Source Optical Emission Spectroscopy

NBTF – SPIDER Diagnostics Data Acquisition

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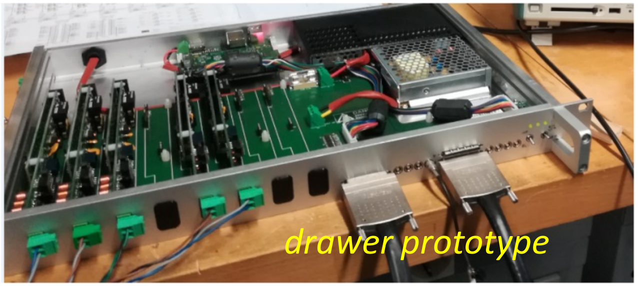
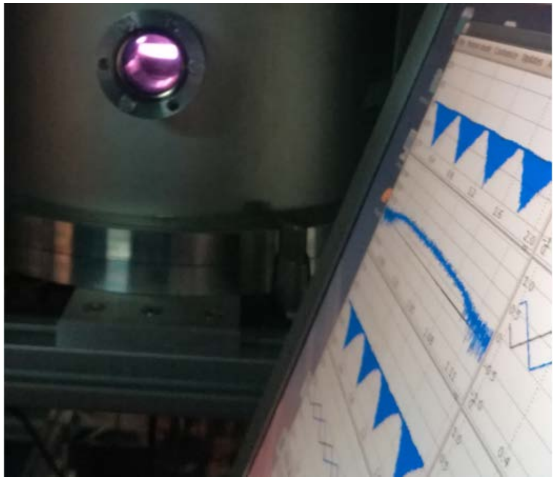
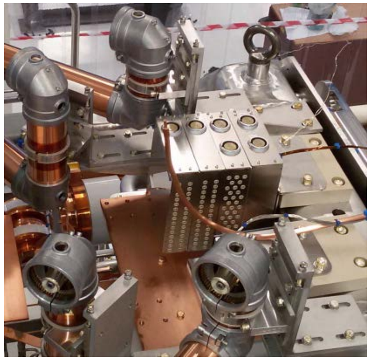
Electrostatic Probes

Installed on Bias Plate and Plasma Grid (84 sensors)

- Single sensor (Isat) or coupled to refer. electrode (V-I)
- In-vacuum RF compensation circuit ~1.5 m from sensor
- Shielded cables: HV bushing -Transm Line - HV deck
- Wiring table, continuity & insulation verified
- Custom front end electronics - each channel:
  - isolated DC/DC converters &
  - probe signal isolated from DAQ.


drawer prototype






Plasma Grid cabinet


Bias Plate cabinet

Real-time Software Framework

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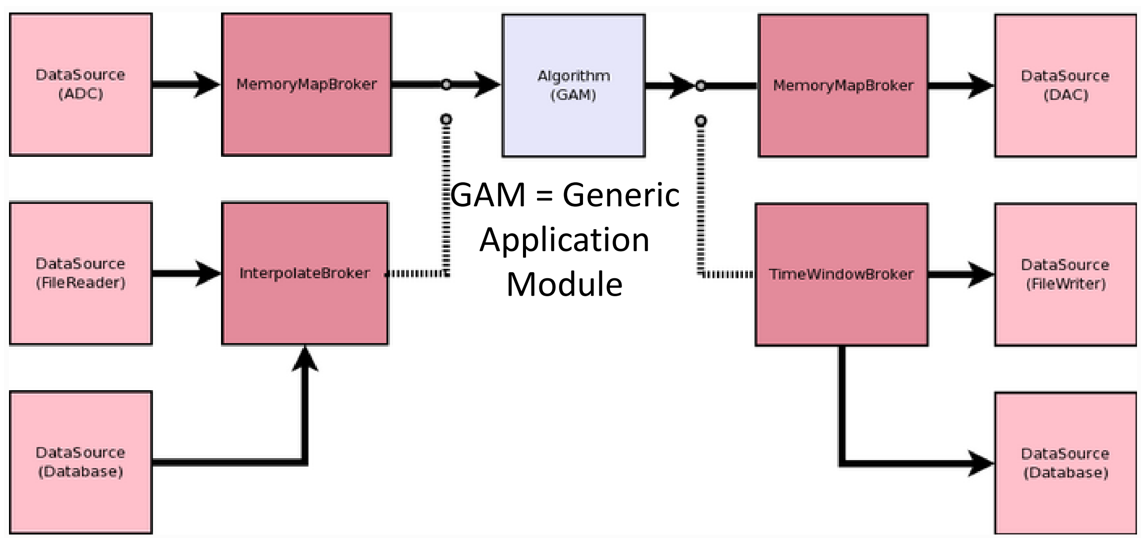
MARTe (Multithreaded Application Real-Time executor)

CNR CONTRIBUTION

- Collaborative development of software framework for real-time applications
- https://vcis.f4e.europa.eu/marte2-docs/master/html/



Marte real-time and simulation environment

IMPACT and CHALLENGES

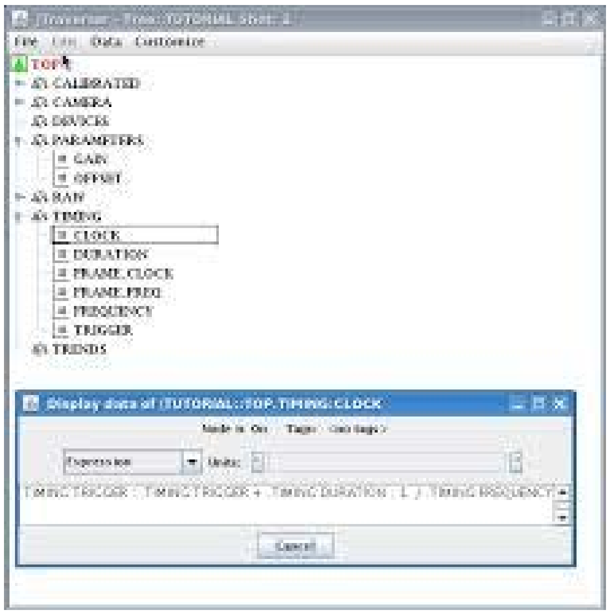
- Portable, real-time software framework in use in several fusionexperimental devices (JET EU, RFX Italy, COMPASS Czech Republic, KSTAR Korea).
- Considered as ITER real-time software framework for plasma control.

Data Management Software Framework

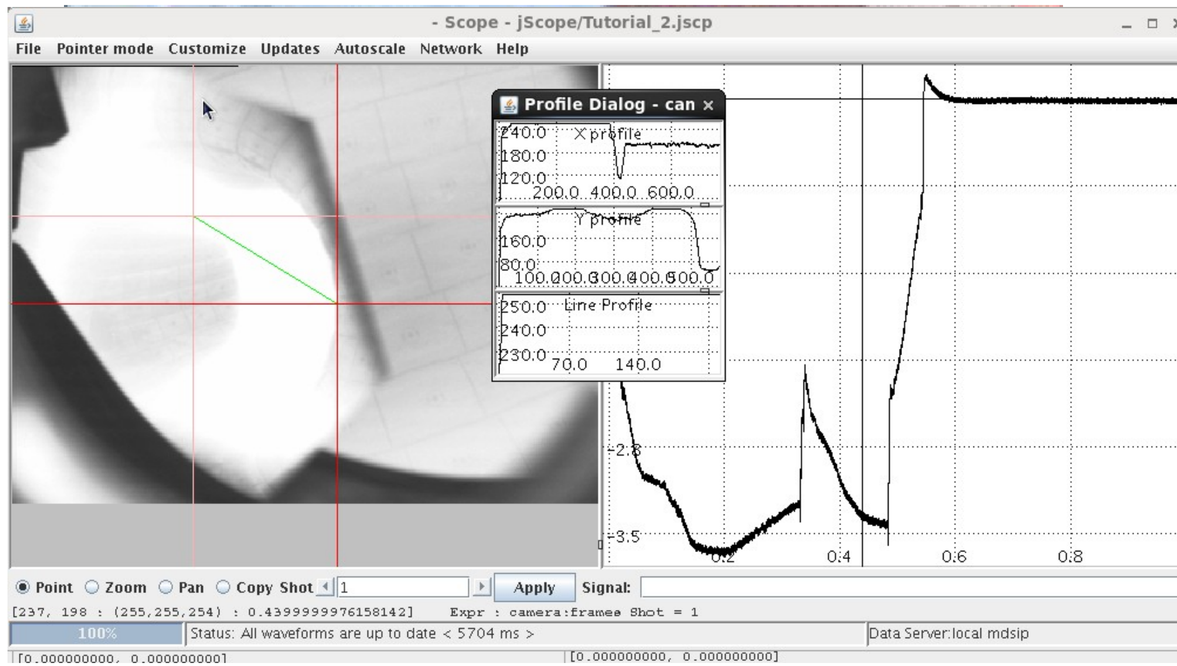
MDSplus (https://mdsplus.org/)

CNR CONTRIBUTION

– Collaborative development of software framework for data management



jTraverser: tool for exploring and editing data structure



jScope: tool for data access and display

IMPACT and CHALLENGES

- Standard de-facto in fusion research for data management, MDSplus is used in most fusion experimental devices (RFX-mod Italy, Wendelstein 7-X Germany, Alcator C-Mod and DIII-D United States, TCV Switzerland, KSTAR Korea, EAST China, W-7X Germany, SST-1 India).
- Challenge: Support of new generation, long-pulse experiments