Insegnamenti per il XXXVIII ciclo DAUSY

Per il corso di dottorato nazionale in *Autonomous Systems* DAUSY si integra l'offerta didattica della Scuola di dottorato per il XXXVIII ciclo (A. A. 2022-2023) con i seguenti 11 insegnamenti tutti afferenti al SSD ING-INF/04 per un totale di 18.5 CFU:

1) Linear Algebra for Control Applications, SSD ING-INF/04, 2 CFU

   Syllabus:

   - Vectors: inner products, norms, main operations (average, standard deviation, ...)
   - Matrices: matrix-vector and matrix-matrix multiplication, Frobenius norm,
   - Complexity, sparsity
   - Special matrices: Diagonal, Upper Triangular, Lower triangular, Permutation (general pair), inverse and orthogonal
   - A square and invertible: LU decomposition (aka gaussian elimination), LU-P decomposition, Cholesky decomposition
   - Ax=b via LU-P decomposition: forward and backward substitution
   - (sub)Vector spaces: definitions, span, bases (standard, orthogonal, orthonormal), dimension, direct sum, orthogonal complement, null space, orthogonal complement theorem
   - Gram-Smith orthogonalization and QR decomposition (square and invertible A, general non-square)
   - Ax=b via QR decomposition. LU-P vs QR
   - Linear maps: image space, kernel, column and row rank
   - Fundamental Theorem of Linear Algebra (Part I): rank-nullity Theorem, the 4 fundamental subspaces
   - Eigenvalues/eigenvector and Shur decomposition
   - Projection matrices: oblique and orthogonal, properties
   - Positive semidefinite matrices: properties and quadratic functions, square root matrix
   - Properties of A'A and AA' and Polar decomposition
   - Singular Value Decomposition: proofs and properties
   - Pseudo-inverse: definition and relation to SVD
   - Fundamental Theorem of Linear Algebra (Part II): special orthogonal basis for diagonalization
   - Least-Squares: definition, solution and algorithms
   - Ill-conditioned problems vs stability of algorithms, numerical conditioning
   - Regularized vs truncated Least-Squares

2) Stochastic approaches in Systems Biology, SSD ING-INF/04, 1.5 CFU

   Syllabus:

   - The kind of chemical reactions, and their mathematical representation: the stoichiometric matrix. Mass action law and fluxes
   - The stochastic approach: Chemical Master Equations (CME). CMEs modeled by Continuous-Time Markov Chains
   - The Gillespie Algorithm
   - Moment computations

- The Langevin equation
- Examples from enzymatic/metabolic reactions and gene transcription networks

3) Duality-based decentralized and distributed optimization, SSD ING-INF/04, 1 CFU

   Syllabus:

   Systems schemes and architectures: centralized and non-centralized approach.
   Preliminaries on unconstrained and set constrained optimization and basics on convex optimization.
   Duality (Lagrange multipliers theory) and duality based algorithms: waterfilling, dual ascent method (DAM), Augmented Lagrangian Method (ALM), Alternating Direction Method of Multipliers (ADMM).
   Decentralized optimization problem set up and duality-based methods: DA, ALM, and ADMM for separable convex programming.
   Distributed optimization problem set up and duality-based methods: DA and ADMM for separable convex programming, distributed waterfilling for coupled convex programming.
   Motivating examples and case studies.

4) Analysis and control of cyber-physical systems, SSD ING-INF/04, 3 CFU

   Syllabus:

   - Introduction to CPS
   - Review on stability notions for nonlinear systems
   - Metric transition systems and their relations
   - Regular languages
   - Symbolic models for stable nonlinear systems
   - Control design and efficient algorithms
   - Diagnosability and predictability
   - Extensions to nonlinear systems with disturbances, possibly unstable nonlinear systems, time-delay systems, networked and networks of nonlinear systems
   - Applications to power grids, biological systems and chemical processes

5) Fault Detection Techniques in Condition Monitoring: Model-Based and Data-Driven Methods, SSD ING-INF/04, 1 CFU

   Syllabus:

   - Issues in Model-Based Fault Diagnosis
   - Fault Detection and Isolation (FDI) Methods based on Analytical Redundancy
   - Model-based Fault Detection Methods
   - Issues in Model-Based Fault Diagnosis
   - Model Uncertainty and Fault Detection
   - The Robustness Problem in Fault Detection
   - System Identification for Robust FDI
   - Fault Identification Methods
   - Modelling of Faulty Systems
   - Residual Generation Techniques

- The Residual Generation Problem
- Fault Diagnosis Technique Integration
- Fuzzy Logic for Residual Generation
- Neural Networks in Fault Diagnosis
- Residual Robustness to Disturbances
- Application Examples

6) Introduction to modeling, analysis and control of complex systems, SSD ING-INF/04, 1 CFU

   Syllabus:

   Definition of a complex systems.
   Examples: wireless sensor networks; compartmental systems
   Elements of matrix theory
   Elements of graph theory
   Linking graphs and matrices
   Collective behaviors: consensus dynamics
   Elements of control of network dynamical systems

7) Linear and nonlinear Kalman filtering: theory and applications, SSD ING-INF/04, 1.5 CFU

   Syllabus:

   · A general dynamic estimation problem in state-space form
   · Recursive Bayesian filtering
   · Kalman filter as recursive Bayesian filter in the linear Gaussian case
   · Beyond the Kalman filter: nonlinear filters for nonlinear and/or non-Gaussian estimation problems (extended Kalman filter, unscented Kalman filter, particle filter, Gaussian sum
   · filter).
   · Theoretical limits on the quality of estimation
   · Applications to surveillance, robotic navigation and environmental data assimilation.
   · Research on multi-agent and/or multi-object estimation.

8) Modeling and simulation of biological and medical systems, SSD ING-INF/04, 3 CFU

   Syllabus:

   - Review of basic concepts of biology and probability; deterministic vs. stochastic approach.
   - Stochastic approach: Reaction Networks, Continuous-Time Markov Chains; the Master Equation and its properties, stationary distribution, the macroscopic equation, one-step processes.
   - Mesoscopic models: the Langevin Equation and the Wiener Process.
   - Deterministic approach: ordinary differential equation (ODE) models.
   - Modeling, quantitative and qualitative analysis, simulation and control examples.
   - Numerical simulation of deterministic and stochastic systems.
   - Biological and biomedical applications.

9) Modeling, filtering and controlling aerospace systems, SSD ING-INF/04, 2 CFU

Syllabus:

Basic notions on dynamical systems, stability, linearization

Aerospace topics:
space missions
coordinate reference systems;
rotations and translations;
rigid body attitude kinematics and dynamics;
orbital dynamics
modeling and simulation of space missions in MATLAB/Simulink
environmental disturbance
actuation system

Filtering techniques:
Kalman filter
Extended Kalman filter
Particle filter
Multiple-weight particle filter

Control techniques:
state-feedback;
linear quadratic regulator
proportional integral derivative
sliding-mode control
model predictive control (classical and robust).

10) Navigation systems for autonomous systems, SSD ING-INF/04, 1.5 CFU

Syllabus:

Introduction to the Navigation problem.
Reference frames.
Inertial sensor technologies: gyroscopes and accelerometers.
Non-inertial sensors: magnetometers, GPS etc.
Navigation Equations
Integrated inertial navigation systems.
Notions of visual-based navigation.
Examples.

11) Optimal control for Climate change and air quality, SSD ING-INF/04, 1 CFU

Syllabus:

- Modelling and control real-world systems: applications and challenges.
- Fundamentals of air quality and climate change control: objectives and constraints.
- Introduction to the application of optimization algorithm in control
- Application, examples and future