Besides the courses listed below, SDIA (Scuola di Dottorato di Ingegneria e Architettura) offers some additional common courses for all PhD schools within the framework of the Department of Engineering and Architecture. In particular, the following two courses are offered:

- **Introduzione ai metodi e agli strumenti della Ricerca scientifica**
- **Study skills: English for Academic Purposes**

Please note that some of the following courses will be activated only if a minimum of 3 participants will be reached. You are required to contact the reference professor.

Title: Compliant Design of Embedded Systems

Course held by Carlo Concari

E-mail reference professor: carlo.concari@unipr.it

2 CFU

Semester: II

Short Course Description

The aim of the course is to provide the basic notions related to designing embedded hardware and firmware compliant with industrial standards (safety, interoperability, maintainability). Course contents:
Embedded hardware for compliant systems (1 hr)
Structured approach to firmware design (1 hr)
Implementation: the building system (1 hr)
Software testing and documentation (1 hr)
Version control systems (1 hr)
Safety standards (1 hr)
Coding standards (1 hr)
Real-time computing (2 hr)
Watchdogs (1 hr)
Bootloaders (1 hr)
Model-based design (1 hr)

Title: Introduction to Convex Optimization

Course held by Prof. Marco Locatelli

E-mail reference professor: marco.locatelli@unipr.it

1.5 CFU

Semester: second

Short Course Description

- Convex sets and convex cones
- Cones of nonnegative, semidefinite and copositive matrices
- Convex functions: different definitions and operations preserving convexity
- Convex optimization problems. Equivalence between local and global minimizers. Examples.
- Optimality conditions: unconstrained and constrained case (KKT conditions)
- Lagrangian duality: weak and string duality
- Convex envelopes
- Interior-point methods and barrier functions: complexity of convex optimization problems
- Some applications
- How to use existing solvers

Title: Methods of Probabilistic Robotics

Course held by Prof. Dario Lodi Rizzini

E-mail reference professor: dario.lodirizzini@unipr.it

2 CFU

Semester: Second

Short program:

The goal of this course is to provide an overview of the concepts of probabilistic robotics and of the main localization and mapping methods. Practical demonstrations with software tools used by research community will support the exposition. The main program is organized as follows: definitions and estimation methods, localization and mapping problems, data association, and sensor registration.

1. Representation of Uncertainty
- Motivation and examples
- Probability density functions, function of random variables, normal distribution
- Propagation of uncertainty
2. Bayesian filters
- State estimation for localization and mapping
- ML and MAP criteria
- Parametric filters: Kalman filters, EKF, UKF (hints)
- Derivation of KF
- EKF for localization and SLAM
3. Graphical models
- Full SLAM problem: derivation
- Least-square SLAM
- Models for graphical formulation: landmark-based, pose graph, perturbation operator
- Practical: graphical SLAM backend g2o
4. Localization and Mapping Issues

- Map models: landmarks, occupancy grid maps
- Data association methods: NN, JCBB, correspondence graphs
- Practical: data association

Title: Quantum Algorithms and Quantum Compiling

Course held by Prof. Michele Amoretti and Dr. Davide Ferrari
E-mail reference professors: michele.amoretti@unipr.it, davide.ferrari1@unipr.it
4 CFU
Semester: second

Course Description

This course will present quantum computing from a computer engineering perspective. The first part will recap the basic concepts of quantum mechanics and quantum information. The second part will focus on quantum algorithms and quantum compilers, considering the case of a single quantum processor as well as the more challenging scenario of distributed quantum computing. Practical experiences will be proposed, introducing the student to software libraries for programming quantum devices.

Short program:

[Michele Amoretti, 6 hours]
1. Introduction to quantum computing
2. Linear algebra (a refresher)
3. Postulates of quantum mechanics
4. Quantum information

[Davide Ferrari, 18 hours]
5. Quantum gates and basic quantum circuits
6. Quantum algorithms: design techniques
7. Grover, QFT, VQA and other major quantum algorithms
8. Quantum compiling on single node
9. Quantum networking and Quantum Internet
10. Distributed Quantum Computing

Title: Virtual constraints for mechanical systems

Course held by Luca Consolini (also via Teams)

E-mail reference professor: luca.consolini@unipr.it

1 CFU

Semester: second

Short Course Description:

A *virtual holonomic constraint* (VHC) for a mechanical system with configuration vector q is a relation of the form $h(q)=0$ that can be made invariant via feedback. In the past decade, VHCs have emerged as a valuable tool to solve various motion control problems.

The presentation will be focused on the challenging case of *underactuated systems*, in which the enforcement of the VHC requires appropriate feasibility conditions. These conditions are satisfied if the constraint function h is obtained as the solution of a differential equation, named *virtual constraints generator*.

The presentation includes some results on **the energy regulation of VHCs** and presents some applications to the *control of the pendubot, the PVTOL aircraft, the bicycle, the spherical pendulum, and the synchronization of mechanical systems*.

Title: Statistical bases of Machine Learning

Course held by Prof. A. Bononi

E-mail reference professor: alberto.bononi@unipr.it

4 CFU

Semester: first

Short program:

Course covers

1) a review of probability and the Bayesian statistical analysis underlying ML (regression, classification)
2) extensions to generalized linear models as a basis to neural networks and other kernel-based methods.
3) supervised learning for both regression and classification.

Details can be found at: http://www.tlc.unipr.it/bononi/didattica/ML_PhD/ML_PhD.html

Title: Introduction to Model-Based Design for dynamic systems

Course held by Prof. Alessandro Soldati

E-mail reference professor: alessandro.soldati@unipr.it

3 CFU

Semester: Second

This course gives and introduction on the numerical modeling of dynamic systems, as a prerequisite for their accurate design and to develop control algorithms, when needed. Both physics-based and data-based models are covered, as well as several model validation techniques, as needed by the good practices of Model-Based Design in the V-model workflow for safety-critical systems.

Short program:

- Abstraction levels, system partitioning and the V-model
- Unit testing, static code analysis and automatic test-benches and documentation
- Numerical analysis for real-time computation
- Numerical analysis for the simulation of dynamic systems
- Numerical techniques for experimental data processing and acquisition
- MIL, SIL, PIL and HIL validation techniques

Title: Reliability of Power Electronic Circuits
Course held by Prof. Alessandro Soldati

E-mail reference professor: alessandro.soldati@unipr.it

3 CFU

Semester: Second

Short program:

- Design-for-Reliability in power electronics (2 h)
- Lifetime models for power system components (2 h)
- Simulation workflow for reliability prediction [tutorial] (2 h)
- Gate drivers for power electronics devices (2 h)
- Active gate drivers for wide bandgap devices (2 h)
- Active thermal control of power electronics (2 h)
- Faults in power electronics (2 h)
- Power electronics diagnostics (2 h)
- Condition monitoring (2 h)
- Advanced sensing and logging for power system control and reliability (2 h)
- Counting techniques (2 h)
- Design of advanced sensing and driving circuits for power electronics [tutorial] (2 h)

Title: Elements of thermography and thermal imaging
Course held by Prof. A. Soldati, F. Bozzoli, L. Cattani (in collaboration with the PhD in Industrial Engineering)

E-mail reference professor: alessandro.soldati@unipr.it

2 CFUs: (8 lectures, 2h each)

Semester: second (June-July)

This course gives the fundamentals of quantitative thermography, i.e., the use of thermal imagers (special cameras sensitive to infrared radiation) to quantitatively measure temperatures without contact and possibly from "long" distances. The applications range from Power Electronics to Heat Transport, from building analysis to diagnostics and prognostics.

Short program:

1. Introduction to thermography (Bozzoli/Cattani)
2. Temperature measurement properties and contact sensors (Soldati)
3. Principles of thermal imaging (Bozzoli/Cattani)
4. Thermal imagers: calibration, compensation, environmental effects (Soldati)
5. Thermography applications in Power Electronics (Soldati)
6. Thermography applications in Heat Transfer (Bozzoli/Cattani)
7. Postprocessing of radiometric data (Soldati/Cattani)
8. Hands-on: thermal cameras in action! (Soldati)