Annex 1. Syllabus of the first year modules

A1.1 The first semester modules

French, Italian, Polish, Spanish Language		
Credits: 4 Semester 1 **Compulsory: Yes**		
Format	Lectures / Conversation 50 h	Private study 50 h
Lecturers: Language departments in ECN, WUT, UJI and UNIGE		
Objectives: Allow the student to achieve a sufficient oral and written comprehension of the local language of the hosting country. As well as an introduction to country culture. **Organization:** The language will be offered in 2 options: Beginners; Advanced (for those who have a previous experience in the language); **Contents:** Culture lectures, conversations, reading, and writing exercises		
Abilities: After completing this course: The students will be able to communicate, speak and write, everyday life requirements, The advanced group will be able also to read and write texts related to scientific topics.		
Assessment: 50% of the mark derived from a continuous evaluation, 50% derived from a final exam.		
Recommended texts: the texts will be given by tutors		

Modelling and control of manipulators

Credits: 6 Semester 1
Compulsory: Yes

Format	Lectures 30 h	Examples 20 h	Private study 100 h

Lecturers: P. MARTINET (ECN), C. ZIELINSKI (WUT), G. CASALINO (UNIGE), A. MORALES (UJI)

Objectives: This course presents the fundamentals of the modelling and control techniques of serial manipulators. Topics include robot architectures, geometric modelling, kinematic modelling, dynamic modelling and its applications, classical PID controller and computed torque controller.

Contents:
The following subjects will be treated:

- Robot architectures, joint space, operational space;
- Homogenous transformation matrices;
- Description of manipulator kinematics using modified Denavit and Hartenberg notations;
- Direct geometric model;
- Inverse geometric models using Paul's method, Piper's method and general methods;
- Calculation of kinematic Jacobian matrix;
- Inverse kinematics for regular and redundant robots;
- Dynamic modelling using Lagrange formalism;
- Dynamic modelling using recursive Newton-Euler method;
- Trajectory generation between two points in the joint and operational spaces,
- Classical PID control
- Computed torque Control.

Practical Work: Exercises will be set, which will involve modelling some manipulators, and simulation of control laws.

Abilities: After completing this course the students will be able to:

- Understand the fundamentals of the mathematical models of serial robot manipulators and their applications in robots design, control and simulation.
- Understand the effect of the kinematic parameters on the manipulator characteristics.
- Use the most convenient methods to obtain the required models,
- Understand practical applications of the mathematical modelling of manipulators,
- Use symbolic and numerical software packages (Matlab, Simulink, Maple, Mathematica, …).

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:

- W. Khalil, and E. Dombre, *Modelling, identification and control of robots*, Hermes Penton, London, 2002.

Further readings:

- C.Canudas, B. Siciliano, G.Bastin (editors), *Theory of Robot Control*, Springer-Verlag, 1996.
- J. Angeles, *Fundamentals of Robotic Mechanical Systems,* Springer-Verlag, New York, 2002.

Control of linear multivariable systems

Credits: 5 Semester 1
Compulsory: No

Format	Lectures 25 h	Examples 15	Private study 85 h

Lecturer: G. LEBRET (ECN), G. CANNATA (UNIGE), J. M. SANCHEZ (UJI)

Objectives: The aim of the course is to give a methodology for the design of a control law for multivariable linear time invariant systems (MIMO LTI systems). This methodology is developed in the state space approach and is based on the concept of the "Standard Problem".

Contents:
The following subjects will be addressed:
- State space equations and solutions.
- Controllability, observability.
- Static state feedback control law.
- Observer synthesis and observer based controller.
- Specification of a control problem in terms of a standard problem.
- Regulator problem with internal stability,
- Internal model principle,
- Linear quadratic method of regulator synthesis,
- The concept of robustness by loop transfer recovery,
- Optimization H2 (or LQG),
- Methodology of control of multi-variable systems.

Practical Work: Control of different laboratory systems using Matlab and dspace.

Abilities: After completing this course the students will be able to:
1. analyze the properties (controllability, …) of a linear multivariable systems,
2. design an observer based controller,
3. define the standard problem (multivariable servo-regulation problem) for a linear (or linearized) multivariable system,
4. give a solution to the standard problem which insure robust stability and robust asymptotic performances to the closed loop system.

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts: The notes of the course will be given by lecturer..

Further readings:

- T. Kailath, *Linear Systems*. Prentice-Hall, New Jersey, 1980.
- G.F. Franklin, J.D. Powell and A. Emami-Naeini, *Feedback Control of Dynamic Systems* (Second Edition). Addison-Wesley, 1991.
- K.J. Aström, B. Wittenmark, *Computer-Controlled Systems, Theory and Design*. Prentice Hall, New Jersey, 1990.
- W.M.Wonham, *Linear Multivariable Control: A Geometric Approach* (Third Edition). Springer Verlag, New York, 1985.
- K. Zhou, with J. Doyle Essentials of Robust Control (Third Edition). Prentice Hall, New Jersey,1998.

Real-time systems			
Credits: 5 Semester 1 **Compulsory: No**			
Format	Lectures 25 h	Guided project 15 h	Private study 85 h
Lecturer: B.J. KUBICA (WUT), M. CHETTO (ECN), F. Pla (UJI), A. SGORBISSA (UNIGE)			

Objectives: By attending the course, the student will learn how to deal with issues concerning real-time applications and real-time operative systems, real-time design and programming, embedded systems.

Contents:

Real-time operating systems

- Basic principles;
- Real-time scheduling algorithms for periodic tasks: Rate Monotonic, arliest
- Deadline First, Deadline Monotonic;
- Real-time scheduling algorithms for aperiodic tasks: scheduling in background,
- Polling Server, Deferrable Server;
- Protocols for accessing shared resources: Priority Inheritance, Priority Ceiling.

Soft real-time systems

- Real-time programming in Posix;
- Thread, mutex and conditional variables;
- Rate Monotonic on Posix Linux;
- Periodic servers;
- Interprocess communication for real-time systems.

Hard real-time systems

- QnX, VxWorks, Windows CE
- RTAI: periodic and aperiodic tasks; communication mechanisms.

Fundamentals of real-time programming for embedded systems.

- General overview of existing families of micro-controllers, DSPs, FPGAs, ASICs.
- Basics of development for embedded systems: coding, compiling, linking, downloading, executing.
- Different kinds of memory devices and memory organization; basic I/O operations; Buses and communication channels.
- Interrupt-driven programming.

Abilities: At the end of the course the student will be able to

- Correctly state and solve problems concerning the design of real-time applications,
- Implement real-time applications in Linux Posix and RTAI;
  - Design event-driven, embedded real-time applications for micro-controllers.

Assessment: 30% laboratory work, 70% end of semester examination.

Recommended texts:

- Giorgio C. Buttazzo, Hard Real-time Computing Systems, Kluwer Academic publishers, 1997.
- Q. Li, C. Yao. Real-Time Concepts for Embedded Systems. CMP Books, 2003.

Further readings:

- will be provided by lecturer.

Basics of Automation and Control

Credits: 4 Semester 1

Compulsory: No

Format	Lectures 30 h	Examples 15	Private study 85 h

Lecturer: C.Rzymkowski (WUT)

Objectives: The aim of the course is to give a methodology for the design of a control law for multivariable linear time invariant systems (MIMO LTI systems). This methodology is developed in the state space approach and is based on the concept of the "Standard Problem". Introduction to mathematical modelling - Laplace Transform as analysis and design tool for Control Systems. Transient and Frequency response analyses. Stability system analyses.

Contents:
The following subjects will be addressed:
The objective of the course is to gain the following abilities:
- ability to transform the functions using Laplace transform,
- ability to describe the control system in Laplace domain,
- ability to create and simplify the block diagrams of controled objects,
- ability to evaluate the typical system responses for standard inputs,
- ability to describe and analyse the control system in time and frequency domains.
- applying basic stability criteria.

Practical Work: Control synthesis of basic systems

Signal processing

Credits: 5 Semester 1
Compulsory: No

Format	Lectures 25h	Tutorials 15h	Private study 85 h

Lecturers: W.Kasprzak (WUT), E.Le Carpentier (ECN), P. García (UJI)

Objectives: To present the methods of description and transformation of deterministic signals for both continuous and discrete time cases. To present also basic knowledge about random signals representation.

Contents:

Analog and digital signal conversion.
Continuous and discrete signal processing.
Linear and nonlinear systems.
Common signal decompositions.
Convolution – its principle and impulse response.
Common impulse responses, convolution properties, correlation.
Fourier transform properties: applications of Fourier transform - spectral analysis of signals, frequency response of systems.
Discrete Fourier transform. Fast Fourier transform.
Introduction to digital filters. Moving average filters. Windowed-sinc filters. De-convolution and optimal filters. Recursive filters. The z-transform and Chebyshev filters. Audio and image processing.
Random signals: summary on random variables: cumulative distribution, probability density function, joint and marginal distributions;
Random signal characterization; basic properties: stationarity, ergodicity, broad-sense stationarity;
Basic signals: definition and validity domain;
Time analysis (correlation) and spectral analysis (power spectral density) of stationary signals;
Fourier analysis, Wiener-Khintchine theorem;

Abilities: The students will be able to:

Represent continuous signals by their discrete equivalents,
Decompose complex signals,
Analyze the signals in Fourier domain,
Design the basic filters for signals processing,
Apply the filter to process the signal,
Analyze random signals

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:

[1] Steven W. Smith, *The Scientist and Engineer's Guide to Digital Signal Processing*. Second Edition, California Technical Publishing, San Diego, CA, 1999, on-line: www.dspguide.com.

[2] A.V. Oppenheim, R.W. Schafer, J.R. Buc, *Discrete-Time Signal Processing. Second Edition.* Prentice-Hall 1999.

Further readings: will be provided by lecturer.

Computer Science 1			
Credits: 5 Semester 1 **Compulsory: No**			
Format	Lectures 30	Laborsatories: 30h	Private study 85 h
Lecturers: J.Rokicki (WUT)			

Objectives: To give the students the fundamentals of programming skills and methods.

Contents:
Basic information related to operating systems and computer networks. Word-processing and spreadsheets used in typical engineering applications. Programming language C - variables and their types, arithmetical and logical operations, control statements, functions, tables and pointers, structures.
Input and Output. Code examples. Basic algorithms (sorting), simple numerical methods. Practical programming skills.

Advanced and Robot Programming			
Credits: 5 Semester 1 **Compulsory: No**			
Format	Lectures 16 h	Tutorials/Labs 32 h	Private study 50 h
Lecturers: F. MASTROGIOVANNI (UNIGE), G. GARCIA (ECN), R. ZACCARIA (UNIGE)			

Objectives: To give the students the fundamentals of:
- C++ programming
- Industrial robot manipulator programming using specialized robot languages.

Contents:
- C++ programming
  - Functions, passing by value and by reference, constant references, pointers.
  - Static and dynamic arrays, multi-dimensional arrays, vectors, strings.
  - Classes, objects, attributes, methods, heritage, virtual methods.
  - Code organization.
  - Operator overloading.
  - Using C++ libraries.
- Industrial manipulator programming
  - The different levels of programming,
  - Tools for teaching locations,
  - Robots, sensors and flexibility,
  - Synchronous vs asynchronous motions, guarded motions,
  - Tool-level programming,
  - Object level programming,
  - Real-time aspects of robot programming,
  - The V+ language, including its real-time aspects and sensor-handling capabilities.
  - Introductory concepts about ROS

Practical Work: C++ labs are essentially oriented towards understanding and using C++ libraries and good programming practice.
As to industrial robot programming, the students will be able to practice with a setup of two

Stäubli industrial robots, a Puma 560 and a RX 90 programmable in V+. The robots are equipped with a belt conveyor, and a number of sensors.
Abilities: After completing this course, the students will be able to: • Program in C++, especially using existing libraries like openCV. • Analyze, program and test complex tasks on industrial robots in V+.
Assessment: 50% continuous assessment, 50% from end of semester examination.
Recommended texts: 1. C. Blume, W. Jakob, *Programming Languages for Industrial Robots*, Springer Verlag. 2. Stäubli: RX Robots Technical Documentation, 2001. 3. Bruce Eckel, Thinking in C++, volumes 1 and 2, 2007. **Further readings:** will be provide by the lecturer

Computer vision

Credits: 5 Semester 1 **Compulsory: No**			
Format	Lectures 24h	Tutorials/examples 16h	Private study 85h
Lecturers: W.KASPRZAK (WUT), P. MARTINET (ECN), F. SOLARI/S. SABATINI (UNIGE), F. PLA (UJI)			

Objectives:
This course presents the fundamentals in computer vision. Topics include camera modelling, camera calibration, image processing, pose estimation, multi view geometry, visual tracking, and vision based calibration.

Contents:
Image formation and auto-calibration. Low-level image processing: image normalization, colour spaces, image compression and image filtering. Image segmentation: edge detection, chain and line segment detection, Hough transforms, homogeneous region-, shape- and texture description. Object classification: the potential functions-, Bayes-, k-NN, SVM- and MLP- classifiers. Object recognition: dynamic programming, hypothesis generation-and-test, model-to-image matching and graph search. Image motion estimation: gradient- and block-based optical flow, discrete feature motion and active contour tracking. Camera technology and vision sensor, Camera model (pinhole, omnidirectional, fisheye, …), Visual geometry, Pose estimation (DeMenthon, Lowe…), Multi view geometry (homography, epipolar geometry, …), Visual tracking, calibration (camera, robots…), Computer vision applications, Computer vision tools

Practical Work: Exercises will involve image processing, multi view geometry, camera calibration, pose estimation, visual tracking, Face recognition.

Abilities: The students will be able to:
Know the different image processing methods,
Understand the different properties of images, cameras and geometry
To select the image processing method for the specific purpose.
Process the images for the purpose of getting the required information.
To use the vision for objects recognition and robot localization and guidance
Understand practical applications of the mathematical modelling of visual geometry

Assessment: 30% continuous assessment, 70% from end-semester examination

Recommended texts:

- I. Pitas, *Digital Image Processing Algorithms*, Prentice Hall, New York, 1993.
- O. Faugeras, *Three-dimensional computer vision. A geometric viewpoint*, The MIT Press. Cambridge, Mass. 1993, ISBN: 0262061589
- Richard Hartley, Andrew Zisserman, *Multiple View Geometry in Computer Vision*, Barnes&Nobles, 2nd edition 2004, ISBN-10: 0521540518
- Quang-Tuan Luong, Olivier Faugeras, *The Geometry of Multiple Images- The Laws That Govern the Formation of Multiple Images of a Scene*, MIT Press, March 2001, ISBN: 0-262-06220-8
- T S Huang, *Multiple Calibration and Orientation of Cameras in Computer Vision*, Springer, 2001, ISBN: 3 540 65283 3
- Yi MA, Stefano Soatto, Jana Kosecka, S. Shankar Sastry, *An invitation to 3D vision: from images to geometric models*, Springer, 2004, ISBN 978-0-387-00893-6
- Gari Bradski, Adfrian Kaebler, *Learning OpenCV: Computer vision with openCV library*, O'Reilly Media, 2008, ISBN: 978-0-596-51613-0

Further readings: will be provided by lecturer

Neural networks for classsification and identification

Credits: 5 Semester 1
Compulsory: No

Format	Lectures 30h	Tutorials 15h	Private study 50 h

Lecturers: G. Orzechowski (WUT)

Objectives:
The goal of the class is to present neural networks as tools for pattern classification, function approximation, and system modeling and prediction. Neural methodology will be thus treated as a step in development of dynamic systems. Neural networks are presented as static or dynamic systems whose main distinctive properties are modularity and adaptability. They are presented in the context of classification, function approximation, dynamical system modeling, and other applications.

Contents:
Classification abilities are discussed for contemporary versions of Rosenblatt's perceptron, support vector machines, and multi-layer perceptrons. They are complemented with elements of learning theory and probably approximately correct estimators. Approximation properties of neural networks are outlined for multilayer perceptrons and for radial basis function networks, and connected to linear regression models. In particular, approximation quality and generalization problems are discussed. Back-propagation is derived as an effective way to calculate gradients in large systems. Theoretical abilities of function approximation properties of multi-layer perceptrons and radial basis function networks are also analyzed. Dynamic neural networks are outlined in the context of dynamical system modeling, contents-addressable memories, and combinatorial system optimization. Neural ARMA models will be derived as a generalization of ARMA models, and their properties will be analyzed. Stability of dynamic networks is discussed in the context of system optimization and contents-addressable memories.

Practical Work: Exercises on the application of the neural networks

A1.2 the second semester modules

<table>
<tr><td colspan="4">Group project</td></tr>
<tr><td colspan="4">Credits: 5   Semester 2
Compulsory: Yes</td></tr>
<tr><td>Format</td><td>Lectures 15</td><td>Examples</td><td>Private study 120 h</td></tr>
<tr><td colspan="4">Lecturers: Various local staff</td></tr>
<tr><td colspan="4">Objectives: The aim of this module is to provide students with the opportunity to apply their specialized knowledge to the solution of a real problem, and gain practical experience of the processes involved in the team-based design and testing of a robotic system.

Work contents: The projects contain a mix of theoretical and practical work. The practical work may consist of one or more of the following components: software development, simulation, hardware development. The deliverables always include a report and, if requested by the supervisor(s), software and/or hardware deliverables.

Examples of project subjects given in previous years:
Hybrid localization system for a mobile robot using magnet detection.
Modeling, Identification and Control of 3 DOF Quanser Helicoptor.
Comparison of various temperature control laws.
Development of models for camera calibration and validation.
Calibration of the geometric parameters of the Neuromate robot.
Trajectory planning for pick and place operations: application to the Orthoglide.
Measurement of reaction forces during the walking of Nao
Motion estimation for visual odometry.
Representing environmental sounds using auditory cortical models.
Scheduling of fixed priority tasks for uni-processor systems.
Robust control of an overhead crane. Development of a signal processing tool for maximum entropy reconstruction of 2D NMR spectra</td></tr>
<tr><td colspan="4">Abilities: Each individual student will be expected to have contributed fully in the team's activities, and will be expected to be able to:
Justify the hardware and software design of their team's finished robot.
Use project management tools to organise their activities.
Produce, test, and evaluate a working system.
Deliver appropriate documentation of a professional standard.</td></tr>
<tr><td colspan="4">Assessment: The evaluation is made by a jury which includes the supervisor(s) plus at least two other staff members. It is based on the following items: quality of work, quality of the written report, and final defense in front of the jury. The supervisors can also require a demonstration of the final product. The effectiveness of the team's management of the project, and the understanding and contribution of each team member are also taken into account.</td></tr>
<tr><td colspan="4">Recommended texts: Will be given by the lecturers.</td></tr>
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Mechanical design methods in robotics

Credits: 5 Semester 2
Compulsory: No

Format	Lectures 25 h	Supervised project 15 h	Private study 85 h

Lecturers: K. MIANOWSKI (WUT), S. CARO (ECN), D. CHABLAT (ECN), D. ZLATANOV (UNIGE), M. ZOPPI (UNIGE), C. VILA (UJI)

Objectives: This course presents the overview of the design process – specification, conceptual design, product design. The students will learn basic principles of industrial robot design.

Contents:
The following subjects will be discussed:
- Conceptual design: concept generation, concept evaluation.
- Product design: documentation, product generation, evaluation for function and performance, evaluation for cost, ease of assembly and other measures.
- Computer aids for mechanical design. CAD/CAE/CAM systems.
- The design of robotic production cell.
- Fundamentals of integrated design of control and drive systems taking into account measurement, gearing and transmission systems.
- Design of a serial robot manipulator (using CAD).

Practical Work: CAD design of manipulator.

Abilities: After completing this course, the students will be able to:
- Design a serial robotic manipulator.
- Formulate properly the needed information for conceptual design (requirements),
- Use CAD systems on the basic level for the design of typical mechanism (serial arm),
- Elaborate the design on general level without material, drive systems and actuators consideration,
- Provide the conceptual documentation for the arm design.

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:
- K.C.Gupta, *Mechanics and Control of Robots*, Springer 1997
- J.E.Shigley, J.J.Uicker, *Theory of Machines and Mechanisms,* McGraw Hill 1995.

Further readings: CAD software documentation

Mobile robots

Credits: 5 Semester 2
Compulsory: No

Format	Lectures 24 h	Tutorials 16	Private study 68 h

Lecturers: P. MARTINET (ECN), G. GARCIA (ECN), R. ZACCARIA (UNIGE), W. SZYNKIEWICZ (WUT), J. SALES (UJI)

Objectives: This course presents fundamentals of wheeled mobile robots modelling, control and localization.

Contents: The following subjects will be addressed:

Non holonomic constraint equations,
Classification of robots, using the degrees of mobility and steering,
Posture kinematic model,
Configuration kinematic model,
Motorisation of wheels.
Dynamic models including the contact model,
Trajectory generation,
Controllability and stabilisation, static and dynamic feedback linearization, nonlinear control based on Lyapunov.
Relative localisation: odometry, inertial systems.
Absolute localisation: GPS, sensor fusion,
3D range measurements and goniometry.
Analysis of the observability of robot location.
Path planning

Practical Work: The students will program mobile robots to follow some prescribed trajectories and to implement control laws taking into account the Cartesian localization.

Abilities: After completing this course, the students will be able to:

Generate the motion trajectories considering the robot constraints,
Simulate the robot motion,
Implement suitable control strategy,
Choose an appropriate localization system for a mobile robot,
Design and implement localization systems using various state observers

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:

- C.Canudas, B. Siciliano, G.Bastin (editors), *Theory of Robot Control*, Springer-Verlag, 1996. (chapters 7,8, and 9)
- Ch. Ahikencheikh, A. Seireg, *Optimized-Motion Planning; Theory and Implementation*. John Wiley 1994.
- R.Siegwart I.R. Nourbakhsh, *Intrduction to Autonomous Mobile Robots*, MIT Press second edition 2010. B.Siciliano, O.Khatib,edt , *Robots Handbook*, Springer-Verlag 2008, Chapters 17, 34, 35.

Artificial intelligence			
Credits: 5 Semester 2 **Compulsory: No**			
Format	Lectures 24 h	Examples 16h	Private study 68 h
Lecturers: W. KASPRZAK (WUT), C. ZIELINSKI (WUT), A. TACCHELLA (UNIGE), E. MARTINEZ (UJI), R. ZACCARIA (UNIGE)			

Objectives:
The goal of the course is to present advanced issues of artificial intelligence from the perspective of a computerized autonomous agent

Contents:
The first part covers basic methods of artificial intelligence – the logic of knowledge representation, inference rules and problem solving including: uniformed search, informed search with heuristic functions, constraint satisfaction problems and adversarial games. The second part deals with practical planning and acting of an autonomous agent (i.e., situation space, plan space, plan decomposition, hierarchic decomposition, contingency planning), and with probabilistic reasoning. The third part discusses agent design problems in the area of knowledge acquisition (learning from observations, in neural networks and reinforcement learning), and machine perception (image and speech understanding).

Abilities: After completing this course, the students will be able to:
Produce and analyse the knowledge inference rules,
Acquire the knowledge using: active observation, neural networks processing.
Process the visual information and recognize speech using the machine perception.

Assessment: 30% continuous assessment, 70% from end-semester examination.

Recommended texts:
- S. Russell, P. Norvig, *Artificial Intelligence: A Modern Approach*. Prentice Hall, Upper Saddle River, N.J., 2002.
- Stefano Nolfi, Dario Floreano (2000), *Evolutionnary robotics*, MIT Press.
- S. Russell, P. Norvig, *Artificial Intelligence: A Modern Approach*. Prentice Hall, Upper Saddle River, N.J., 2002.*Problem Solving*, Addison Wesley, 1997.

Further readings:
- G.F. Luger, W.A. Stubblefield, *Artificial Intelligence. Structures and Strategies for Complex Problem Solving*, Addison Wesley, 1997
- J-P. Delahaye, *Formal Methods in Artificial Intelligence,* Oxford 1987

Optimisation techniques

Credits: 5 Semester 2
Compulsory: No

Format	Lectures 24 h	Tutorials / Projects 16	Private study 68 h

Lecturer: F. BENNIS (ECN), W. OGRYCZAK (WUT), C. NATTERO (UNIGE)

Objectives: The lecture presents different theoretical and computational aspects of a wide range of optimization methods for solving a variety of problems in engineering and robotics.

Contents:

- Basic concepts of optimization,
- Gradient based methods,
- Evolutionary algorithms,
- Multi objective optimization methods,
- Robust optimization methods,
- Inverse problem,
- Multidisciplinary optimization problems,
- Programming aspects,

Practical Work: exercises on design and motion planning robotics problem.

Abilities: The students will be able to:

- Understand different theoretical and computational aspects of a wide range of optimization methods,
- Realize the possibilities offered by the different optimization methods,
- Use of optimization toolbox.

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:
R. Fletche, *Foundation of structural optimization.* A unified Approach, John Wiley & Sons, 1987.
Further readings: will be provided by lecturer

Nonlinear control

Credits: 5 Semester 2
Compulsory: No

Format	Lectures 24 h	Examples 16 h	Private study 68 h

Lecturers: F. PLESTAN, C. MOOG (LS2N)

Course objectives: The goal is to give the basis of modern nonlinear control theory. Analysis and control of nonlinear systems are considered using a so-called algebraic approach. Examples taken from robotics or electric drives demonstrate the feasibility of the methodology.

Contents:

- Introduction to the algebraic approach for nonlinear systems and its mathematical tools.
- Structural analysis, concepts of relative degree, of controllability and observability.
- Control methods: feedback linearization, decoupling, reference trajectory tracking.
- Lyapunov functions and their properties.
- Recursive global stabilization by state feedback of nonlinear systems.
- Design of a nonlinear observer. Special observability forms for input-affine systems.
- Observer-based stabilization. Methods to avoid finite-escape time.
- Dynamic output feedback semi-global stabilization.

Practical Work: Exercises, use of computer algebra, case study on an inverted pendulum.

Objectives: After completing this course, the students will be able to:

Understand the theoretical fondamentals on the control of nonlinear systems,
Apply advanced nonlinear control on a variety of robotics systems,
Implement control strategy, and calculate the corresponding observer.

Assessment: 30% continuous assessment, 70% from end-semester examination

Recommended texts:

- G. Conte, C.H. Moog and A.M. Perdon, *Algebraic Methods for Nonlinear Control Systems. Theory and Applications*, Springer-Verlag, 2006.
- A. Isidori, *Nonlinear Control Systems. 2nd edition*, Springer-Verlag, 1989.
- R. Marino and P. Tomei, *Nonlinear Control Design: Geometric, Adaptive and Robust*, Prentice Hall, 1995.

Further readings:

- M. Vidyasagar, *Nonlinear Systems Analysis*, Prentice Hall, 1993.

Robot Programming Methods			
Credits: 5 Semester 2 **Compulsory: Yes**			
Format	Lectures 30h	Tutorials/Labs 30h	Private study 50 h
Lecturers: C. ZIELINSKI (WUT)			

Objectives: To learn the robot programming methods

Contents:
Several historic and currently used specialized robot-programming languages will be presented. Then focus will shift to robot programming frameworks, i.e.: libraries of modules, a pattern according to which they have to be assembled and tools for producing new modules. Robot will be treated as an embodied agent and its operation will be described formally in terms of transition functions. Both sequential and concurrent decompositions of those functions will be considered. Competitive and cooperative composition of results and the definition of complex behaviours will be the subject of presentation. The transition from synchronous to event driven systems will be shown. Deliberative vs. behavioural, fuzzy vs. crisp, deterministic vs. indeterministic systems will be described from the point of view of the definition of the transition functions governing their behaviour. Cooperation and coordination in multi-robot systems will be described. The course will also cover implementation issues, especially programming paradigms (procedural, object-oriented, component based). Error handling and debugging issues will also be explained. The presentation of implementation structures (methods of merging specialized languages and programming frameworks and the influence on the compilation/interpretation of the resulting code) will follow. An introduction to formal languages and how to build a simple compiler of a robot language will be shown. ROS and MRROC++ robot programming framework will be used for presenting examples of complex systems, e.g. capable of two-handed manipulation with force sensing, visual servoing, voice communication and capability to reason. The course will conclude with the description of software for swarms of autonomous robots and coordinated multi-robot systems requiring utility based task allocation.

Abilities:

After completing this course the students will be able to:

- To use the typical robot programming language,
- To elaborate his own robot programming framework for a single robot,
- To specify the programming framework for the multi-robot systems.

Software architectures for robotics

Credits: 5 Semester 2
Compulsory: No

Format	Lectures 16 h	Examples 30 h	Private study 68 h

Lecturers: Fulvio MASTROGIOVANNI (UNIGE) and G. GARCIA (ECN)

Course objectives: A robot is a multi-purpose, multi-form and multi-function machine. It exhibits completely new and unique characteristics with respect to what it is for, how it is structured and what it is able to do. In order to cope with this diversity in form and function, software architectures for robots must be grounded on top of a model enforcing flexibility and efficiency well beyond those developed in other domain applications.
Students will be able to identify stable requirements in different and various scenarios, common design issues and similar approaches to recurrent software development problems while designing new Robotics applications.
Another objective of the module is to make the students familiar with robotics middleware very commonly used in robotics applications, like ROS (Robot Operating System).

Contents:
The following topics will be considered:
- Trends in software development for robots.
- Software environments for robot programming.
- Component-based software frameworks.
- Communication and information flow.
- Management of heterogeneous hardware and software.
- Examples of available programming frameworks and architectures.
- ROS: Robot Operating System.
- Effibox.

Practical Work:
In the lab, the students will develop applications using ROS.

Abilities: After completing the course students will be able to:
- Choose an appropriate architecture and design framework for a given robotic system.
- Identify infrastructural and practical solutions for the problem at hand.
- Develop applications for fairly complex robotic systems using existing middleware.

Assessment: 50% continuous assessment, 50% from end-semester examination

Recommended texts:
- D. Brugali (Ed.). Software Engineering for Experimental Robotics. In Springer Tracts in Advanced Robotics, vol. 30. Springer Berlin / Heidelberg, 2007.
- I. Sommerville. Software Engineering. In the International Computer Science Series. Addison Wesley, 2000.

Embedded Systems			
Credits: 5 Semester 2 **Compulsory: No**			
Format	Lectures 30	Tutorials / Projects 15	Private study 68 h
Lecturer: S. DENEI (UNIGE)			

Objectives:
This course presents the fundamentals of embedded systems from both the architectural point of view and the basics of programming, with particular attention to sensing and actuating devices.

Contents:
- General overview of existing families of micro-controllers, DSPs, FPGAs, ASICs.
- Basics of developing for embedded systems: coding, compiling, linking, downloading, executing.
- Different kinds of memory devices and memory organization.
- On-chip and off-chip peripherals units and basic I/O operations: ADC, DAC, PWM, Parallel port, Counters, Timers.
- Buses and communication channels.
- Interrupt-driven programming.
- Fundamentals of real-time programming for embedded systems.

Practical Work:
Exercises will be set, which will involve design and implementation and testing of real-time code for micro-controllers

Annex 2. Syllabus of the second year modules

A1.1 The third semester modules at ECN

French Language		
Credits: 4 Semester 3 (ECN) **Compulsory:** Yes		
Format	Lectures / Conversation 50 h	Private study 50 h
Lecturers: ECN Language department		
Objectives: Allow the student to achieve a sufficient oral and written comprehension of the local language of the hosting country. As well as an introduction to country culture. **Organization:** The language will be offered in 2 options: Beginners (joint group with 1st semester students), Advanced (for those who have a previous experience in the language); **Contents:** Culture lectures, conversations, reading, and writing exercises		
Abilities: After completing this course: The students will be able to communicate, speak and write, everyday life requirements, The advanced group will be able also to read and write texts related to scientific topics.		
Assessment: 50% of the mark derived from a continuous evaluation, 50% from end of semester examination.		
Recommended texts: the texts will be given by lecturers.		

Remark: if the student is fluent in French, the French language course can be replaced by a scientific course of Emaro+ M2 or by one of the common courses of the French common track of ROBA2 which are given in French for instance (*Modèles et Systèmes* or *Optimisation Techniques*).

Research Methodology

Credits: 5   Semester 3 (ECN)
Compulsory: Yes

Format	Lectures 15 h	Lab 3 h	Private study 70 h

Lecturer: I.Taralova (ECN)

Objectives:

This course aims to provide the students with the necessary skills and tools to carry out and present a research topic. It presents the jobs of researchers and university staff, in research institutions, labs and in R&D departments in companies, and how to apply for them.
This course includes also the bibliographical study for the master thesis topic.

Contents:

- Setting goals and defining objectives of the master thesis;
- Bibliographical research and collecting information;
- Written communication: reports, theses, journal & conference papers;
- Oral communication: research presentations, attending conference & presenting a paper;
- Presentation of the researcher position, and university staff;
- The research institutions in EMARO+ countries;
- How to apply for a faculty position or research institutions in Europe and worldwide;
- Seminars will be organized to present the state of art of advanced topics.

Abilities: After completing this course, the students will be able to:

- Research the background and perform literature review relating to a specified subject;
- Identify key aspects of research work;
- Use a range of techniques to research and collect information;
- Demonstrate an understanding on how research may be evaluated;
- Plan and prepare a research proposal;
- Deliver a satisfactory written report, including correct citation of related works and analysis;
- Understanding the job of the researchers and faculty staff.

Assessment: Written report about related work of his research topic (50%), oral presentation (50%).

Recommended texts:

- J. Collis, R. Hussey, *Business Research A Practical Guide for Undergraduate and Postgraduate Students*, 2nd Edition, Basingstoke: Palgrave, 2003,
- M. Polonsky, D. Waller, *Designing and Managing a Research Project,* Sage, 2005

Sensor based control of complex robots

Credits: 4 **Semester 3**

Compulsory: Yes

Format	Lectures 24 h	Examples, Laboratory 12 h	Private study 60 h

Lecturers: Ph. Martinet (ECN), O. Kermorgant (ECN)

Objectives: This course presents the fundamentals of the modelling and control techniques used in sensor-based control of complex robots. By complex robots, we consider multi arms systems (including Humanoid robots), parallel robot. Topics will include classical kinematic and dynamic robot control (computed torque control) based expressed in joint, Cartesian and sensor space (i.e visual servoing) more generally. A special focus will be done on redundant robot control using task priority formalisms.

Contents:

The following subjects will be treated:

- Kinematic control of robots
- Computed torque control
- Position/Force control
- Sensor based control
- Vision based control (Interaction matrix, 2D, 3D, Hybrid)
- Advanced Vision based control (Omnidirectional, Fisheye, Vision/force, ...)
- Visual servoing applications (manipulators, mobile robots, aerial robots, parallel robots, humanoids ...)
- Point-based and region-based image moments
- Redundancy and task priority
- Unilateral contraints in sensor space (object visibility, obstacle avoidance)
- Multi points control of robots

Practical Work: Exercises will be set, which will involve modelling some visual features, and simulation of different control laws.

Abilities: After completing this course the students will be able to:

Understand the different properties of visual servoing scheme.

- Use the most convenient methods to obtain the required models,
- Understand practical applications of the mathematical modelling of kinematic visual features.

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:

- W. Khalil, E. Dombre: *Modeling, identification and control of robots*, Hermes Penton, London, 2002.
- F. Chaumette, S. Hutchinson, *Tutorial, Visual servo control PART I: Basic approaches,* IEEE Robotics and Automation Magazine, December 2006
- F. Chaumette, S. Hutchinson, *Tutorial, Visual servo control PART II: advanced approaches,* IEEE Robotics and Automation Magazine, March 2007
- Visual Control of Robots: High Performance Visual Servoing, P.I. Corke, Robotics and Mechatronics Series, 2, John Wiley & Sons Inc (November 1996), Language: English, ISBN: 0471969370
- O. Kanoun, F. Lamiraux, P.-B. Wieber, Kinematic control of redundant manipulators : generalizing the task-priority framework to inequality task, IEEE Trans. on Robotics, 2011

Advanced Modelling of Robots

Credits: 5 Semester 3 (ECN)
Compulsory: Yes

Format	Lectures 24 h	Examples 16h	Private study 80 h

Lecturer: S. Briot (CNRS), S. Caro (CNRS)

Objectives: This course presents advanced modelling techniques (geometric, kinematic and dynamic) of robots (tree structure robots, parallel robots, and hybrid robots) composed of rigid links.

Contents: The following topics are treated:

Description of complex mechanical systems (tree-structured or closed loop systems),

Geometric and kinematic models of closed-loop structure robots, constraints equations, mobility analysis, singularity analysis (introduction to DHm convention of tree-structured and closed loop systems)

Workspace analysis of full-mobility and lower-mobility parallel robots

Calibration of geometric parameters

Recalls of dynamics principle (Newton-Euler, Euler-Lagrange, Principle of virtual works) for open and closed-loop mechanism systems

Dynamic modelling of rigid tree-structure robots: the inverse and direct dynamic problems, the base inertial parameters, computation of the ground forces.

Dynamic modelling of rigid parallel robots without and with actuation redundancy: the inverse and direct dynamic problems, the base inertial parameters, computation of the ground forces.

Analysis of the degeneracy conditions of the dynamic model of rigid parallel robots, and singularity crossing

Identification of dynamic parameters

Practical Work: Exercises will be set, involving modelling, identification and simulation of robots. Advanced technical papers from recent international conferences will be analysed and reviewed.

Abilities: After completing this course, the students will be able to:

Understand the fundamentals of the mathematical models of robots and their applications in robot design, control and simulation.

Analyse the mobility of parallel robots and understand the notion of operation modes

Analyse, identify and illustrate the serial and parallel (including the constraint) singularities of parallel robots

Identify the geometric and dynamic parameters of a robot

Use of the best methods to develop the required models of a given architecture

Apply the given techniques to other systems such as mobile robots or passenger cars

Use the convenient numerical schemes for numerical integration.

Use modelling, optimization, and signal processing tool boxes software packages (Matlab, Adams).

Assessment: 30% continuous assessments, 70% from end of semester examination.

Recommended texts:

- S. Caro, lecture notes on "*Geometric and Kinematic Modelling of Serial and Parallel Robots*"
- W. Khalil, E. Dombre, *Modelling, identification and control of robots*, Hermes Penton, London, 2002.
- J. Angeles, *Fundamentals of Robotic Mechanical Systems,* Springer-Verlag, New York, 3rd edition, 2007
- Merlet, J. P., 2006, Parallel Robots (Solid Mechanics and Its Applications), Springer, New York, Vol. 128.
- S. Briot, lecture notes on "Advanced Dynamic Modelling of Robots"
- S. Briot and W. Khalil, *Dynamics of Parallel Robots*, Springer.

Further readings: will be provided during the course

Humanoid Robots

Credits: 4 Semester 3 (ECN)
Compulsory: No

Format	Lectures 20 h	Examples 12 h	Private study: 68 h

Lectures: C. Chevallereau (CNRS), Y. Aoustin (Univ. Nantes)

Contents:

This course presents the fundamentals of control of humanoids for locomotion and manipulation. The students will learn the most common solutions used for stable motion synthesis and control.

The course contains the following items:

- biped locomotion: kinematics and dynamics, modelling of the contact with the ground
- motion synthesis for bipeds : optimization method, simplified models
- passive robots: properties, stability analysis (Poincaré map), extension
- control methods for postural stabilization, walking, and running : ZMP, on line adaptation, stability analysis, foot placement
- humanoid: whole motion control (redundancy)
- manipulation and grasping
- under-actuated hand

Practical Work:

Exercises will be set, which will involve modelling biped, definition of optimal motion, simulation of passive robots, experiments on under-actuated hand.

Objectives:

After completing this course, the students will be able to:

define the walking robot stability considering the static and dynamic condition,
define a control law for a walking robot,
analyse the stability of a control strategy,
synthesize and implement the motion of simple walking robot,
define a control law for a manipulation task

Assessment: 30% continuous assessment, 70% from end of semester examination

Recommended texts:

- C. Chevallereau, G. Bessonnet, G. Abba et Y. Aoustin *Bipedal Robots*, ISTE Wiley, CAM Control Systems, Robotics and Manufacturing Series,
- E. R. Westervelt, J. W. Grizzle, C. Chevallereau, J-H Choi, *Feedback Control of Dynamic Bipedal Robot Locomotion, and Benjamin Morris*, Taylor & Francis/CRC Press, 2007.
- M. Vukobratovic, B. Borovac, D. Surla, D. Stokic, *Biped Locomotion: Dynamics, Stability, Control and Application*, Springer-Verlag , 1990.
- Marc Raibert , *Legged Robots That Balance*, MIT Press, 2000

Further readings:

will be provided during the course

Optimal kinematic design of robots			
Credits: 4 Semester 3 (ECN) **Compulsory: No**			
Format	Lectures 20 h	Examples 12 h	Private study 68 h
Lectures: P. WENGER (CNRS)			

Objectives:

This course presents advance tools and methodologies for the kinematic design of new robots. Both serial and parallel kinematic architectures will be treated. The students will learn how to manage a general kinematic design problem in robotics.

Contents:

The course contains the following items:

- Formalization of relevant criteria for the performance evaluation of robots (accessibility, feasibility of trajectories, dexterity, cuspidality…),
- Methods for the calculation of robot workspace and of the maximal regions of feasible trajectories, taking into account joint limits and obstacles,
- Classification of cuspidal robots (non-singular posture changing robots) and geometric conditions for a robot to be cuspidal/noncuspidal
- Optimal design and placement of serial-type robots in cluttered environments,
- Methods for designing parallel kinematic robots (architecture design, geometric design, coping with singularities and operation modes),
- Application examples in typical industrial cases,
- Application examples for the design of innovative robots.

Abilities:

After completing this course the students will be able to:

- Set an optimal design problem in robotics, taking into account multi-objective criteria,
- Evaluate the kinematic performances of serial and parallel robots,
- Know how to design a cuspidal or a non-cuspidal robot
- Find the best suitable robot for a given task
- Find the best placement of the robot's base,
- Design parallel kinematic robots with given mobility and motion type.

Assessment: 30% continuous assessment, 70% from end of semester examination.

Practical Work:

Exercises will be set, which will involve the optimal kinematic design of typical robotic manipulators (serial and parallel). Simulation and verification using Robotic-CAD systems.

Recommended texts:

- J. Angeles, *Fundamentals of Robotic Mechanical Systems,* Springer-Verlag, New York, 2002,
- P. Wenger : "Performance Analysis of Robots", in *Robot Manipulators: Modeling, Performance Analysis and Control*, E.Dombre, W.Khalil (ed.), ISTE, London, 2006.

Further readings:

- J.P. Merlet, *Parallel Robots*, Second Edition, Springer, 2006.

Autonomous Vehicles			
Credits: 4 Semester 3 **Compulsory: No**			
Format	Lectures 20 h	Examples, Laboratory 12 h	Private study 60 h
Lecturers: P. MARTINET (ECN), E. LECARPENTIER (ECN), C. LAUGIER (Inria)			

Objectives: This course presents the fundamentals of the perception for intelligent and autonomous vehicles. Topics will include Mapping, Decision making process, autonomous navigation and platooning.

Contents: The following subjects will be treated:

- Introduction to IV and ITS application
- Bayesian framework
- Decision process
- SLAM
- Autonomous navigation (ADAS, IPAS)
- Platooning

Practical Work: Exercises will be set, which will involve platoon of autonomous vehicle, SLAM, Bayesian framework and decision process

Abilities: After completing this course the students will be able to:

- Have an overview of an intelligent vehicles capabilities
- Estimate the risk and the situation
- Put in place a decision making process
- Understand the global architecture of an autonomous vehicle and platoon

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:

- **Eskandarian** Azim, Handbook of Intelligent Vehicles, Springer London Ltd Edition, 2012, 1630 pages, ISBN-10: 0857290843, ISBN-13: 978-0857290847
- **Cheng** Hong, Autonomous Intelligent Vehicles, Theory, Algorithms, and Implementation, Series: Advances in Computer Vision and Pattern Recognition, Springer, 2011, 147 pages, ISBN:978-1-4471-2279-1
- Yaobin Chen, Lingxi Li, Advances in Intelligent Vehicles, 1st Edition, Academic Press, Dec 2013, 336 Pages, ISBN : 9780123971999
- Multiple View Geometry in Computer Vision, Richard Hartley, Andrew Zisserman, Barnes&Nobles, 2nd edition 2004, ISBN-10: 0521540518
- Three-Dimensional Computer Vision, Olivier Faugeras, MIT Press, November 1993, ISBN: 0262061589
- An invitation to 3D vision: from images to geometric models, Yi Ma, Stefano Soatto, Jana Kosecka, S. Shankar Sastry, Springer, 2010, ISBN-10: 1441918469, ISBN-13: 9781441918468
- Visual Odometry, Part I - The First 30 Years and Fundamentals, Scaramuzza, D., Fraundorfer, F., IEEE Robotics and Automation Magazine, Volume 18, issue 4, 2011.
- Visual Odometry: Part II - Matching, Robustness, and Applications, Fraundorfer, F., Scaramuzza, D., IEEE Robotics and Automation Magazine, Volume 19, issue 1, 2012
- Simultaneous localization and mapping: part I, Durrant-Whyte, H. ; Australian Centre for Field Robotics, Sydney Univ., NSW ; Bailey, Tim, IEEE Robotics & Automation Magazine, 3(2):99-110, June 2006
- Simultaneous localization and mapping (SLAM): part II, Bailey, Tim ; Australian Centre for Field Robotics, Sydney Univ., NSW ; Durrant-Whyte, H., IEEE Robotics & Automation Magazine, 13(3) : 108 -117, Sept. 2006

From human motion to humanoid control			
Credits: 4 Semester 3 (ECN) **Compulsory: No**			
Format	Lectures 20 h	Examples 12 h	Private study 68 h
Lecturers: S. SAKKA (ECN)			

Objectives: This course makes a review of the necessary steps allowing a software simulation of a captured human motion to control a humanoid robot. It presents the fundamental knowledge on the mechanics of the human body considered as open kinematic chains of rigid bodies.

Contents:

The following subjects will be discussed:

- Human kinematics and dynamics modelling from non-invasive measures
  - Non invasive measurement of human movement, experimental process
  - Experimental, hardware and software artefacts
  - Musculo-skeletal system
  - Human models for robotics applications, approximations
  - Simulation of human dynamics from optical motion capture
- Imitation of human motion using a humanoid robot
  - Kinematics – application to manipulation, upper and whole body movements
  - Dynamics – application to whole-body humanoid motion generation
  - Autonomous behaviors

Abilities: After completing this course, the students will be able to:

- Measure human motion using optical motion capture system
- Model and simulate human dynamics
- Imitate hand, arm and whole body human motion (kinematics) using a humanoid robotic system
- Understand the security and ethics issues of interacting with human beings

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:

- W. Khalil, E. Dombre: *Modeling, identification and control of robots*, Hermes Penton, London, 2002.
- S. Kajita, H. Hirukawa, K. Harada, K. Yokoi: *Introduction à la commande des robots humanoïdes*, Springer, 2009.

Further readings:

will be provided by lecturers

Advanced Visual Geometry			
Credits: 4 Semester 3 **Compulsory:** yes			
Format	Lectures 20 h	Examples, Laboratory 12 h	Private study 68 h
Lecturers: O. KERMORGANT (ECN), D. MARQUEZ GAMEZ (IRT Jules Verne)			

Objectives: This course presents the fundamentals of the advanced vision-based perception algorithms. Vision is one of the most promising senses to be used in robotics, providing important geometrical information on the surroundings of the robot. In this way, two-view geometry extended to multiple-view geometry will be investigated in order to address the difficult problems of relative pose estimation, 3D registration, pose and velocity estimation, and Simultaneous Localization And Mapping. Depth cameras will also be introduced as they are more and more used in robot perception.

Contents: The following subjects will be treated:

- Projective geometry
- Epipolar geometry (Homography, Essential and fundamental matrix)
- Multi view geometry
- Visual odometry
- Pose and velocity estimation
- 3D registration
- Visual SLAM (Mono, stereo)
- RGB-D cameras

Practical Work: Exercises will be set, which will involve pose and velocity estimation, visual odometry, visual SLAM, RGB-D cameras

Abilities: After completing this course the students will be able to:

- Understand what can be done from visual geometry
- Develop algorithms for visual odometry
- Develop algorithm for SLAM application
- Perform 3D registration

Assessment: 30% continuous assessment, 70% from end of semester examination.

Recommended texts:

1. Multiple View Geometry in Computer Vision, Richard Hartley, Andrew Zisserman, Barnes&Nobles, 2nd edition 2004, ISBN-10: 0521540518
2. Three-Dimensional Computer Vision, Olivier Faugeras, MIT Press, November 1993, ISBN: 0262061589
3. An invitation to 3D vision: from images to geometric models, Yi Ma, Stefano Soatto, Jana Kosecka, S. Shankar Sastry, Springer, 2010, ISBN-10: 1441918469, ISBN-13: 9781441918468
4. Visual Odometry, Part I - The First 30 Years and Fundamentals, Scaramuzza, D., Fraundorfer, F., IEEE Robotics and Automation Magazine, Volume 18, issue 4, 2011.
5. Visual Odometry: Part II - Matching, Robustness, and Applications, Fraundorfer, F., Scaramuzza, D., IEEE Robotics and Automation Magazine, Volume 19, issue 1, 2012
6. Simultaneous localization and mapping: part I, Durrant-Whyte, H. ; Australian Centre for Field Robotics, Sydney Univ., NSW ; Bailey, Tim, IEEE Robotics & Automation Magazine, 3(2):99-110, June 2006
7. Simultaneous localization and mapping (SLAM): part II, Bailey, Tim ; Australian Centre for Field Robotics, Sydney Univ., NSW ; Durrant-Whyte, H., IEEE Robotics & Automation Magazine, 13(3) : 108 -117, Sept. 2006

A1.2 The third semester modules at UJI

Research Methodology			
Credits: 6 Semester 3 (UJI) **Compulsory: Yes**			
Format	Lectures 10 h	Examples 0 h	Private study 140 h
Lecturers: R. BERLANGA, G. QUINTANA			

Objectives: This course is intended to provide the student with the necessary skills and tools to carry out and present a research topic. This course is considered also as the background study and collect information part for the master thesis topic, which will be completed during the fourth semester.

Contents:

- Research methodology,
- Written communication: reports, theses, Journal & Conference papers,
- Oral communication: Research Presentations, Attending Conference & Presenting paper,
- Setting goals and defining objectives of the thesis.

Spanish Language		
Credits: 4 Semester 3 **Compulsory: Yes**		
Format	Lectures/ Conversation 50h	Private study 50 h
Lecturers: E. PORTALÉS, J. MARTÍ		

Objectives: The language courses will be offered in different levels from A1 (Beginners) to C2 according to the parameters defined in the Common European Framework of Reference for Modern Languages of European Council.
Students will be evaluated in a initials tests, classes (max 25 people) will be formed according to the test results.

Contents:
Culture lectures, conversations, reading, and writing exercises

Robotic Intelligence			
Credits: 5 Semester 3 (UJI) **Compulsory: Yes**			
Format	Lectures 30 h	Examples 15 h	Private study 80 h
Lecturer: A. PASCUAL DEL POBIL			

Objectives: Introduction to the topic of Machine Intelligence, understood as part of artificial intelligence that deals with those aspects of intelligence related to physical systems that interact in the real world. This intelligent behavior includes objectives such as: adaptation to a changing environment, active perception to interact with a partially unknown environment, explore, to learn, etc.

Contents:

- The study of intelligence. Fundamentals and panoramic
- Robot intelligence: the basics
- Neural networks for adaptive behavior
- Braitenberg vehicles and arquitetura of Subsumption
- Development: from locomotion to cognition
- Evolution, genetic algorithms and self-organizing
- Design principles of autonomous robots

Practical Work: **Laboratory exercises on modelling and development of intelligent systems**

Perception and Manipulation			
Credits: 4 Semester 3 (UJI) **Compulsory: Yes**			
Format	Lectures 30 h	Examples 10 h	Private study 85 h
Lecturer: Pedro J. SANZ			

Objectives:
This course is an indispensable piece of connection between robotic systems and the real world, where physical interaction is crucial. The way we interact with the universe surrounding a robot, is strongly influenced by the ability of perception of the environment implemented in it. Thus, during the physical interaction related to the ability to manipulate their environment, the robot may incorporate more robust and efficient resources to the extent that it is capable to combine different types of sensory information from different perceptual channels. We show that the combination of vision, force / torque and tactile feedback, is a powerful mechanism to attack complex problems of robotics, handling impossible to solve properly this multi-sensorial without cooperation.

Contents: The following subjects will be treated:

- Introduction to Artificial Perception.
- Perception-Action Integration.
- Gripping and Handling Robotics.
- Autonomous vs. teleoperated manipulation
- Introducing Learning Tasks grip.
- Sensory Fusion Technical Information in the Context of Robotic Grasp.
- Case Study-1: Jaume, the Robot Assistant UJI.
- Case Study-2: Towards Autonomous Intervention Underwater Robotics

Cooperative Robotics			
Credits: 5 Semester 3 (UJI) **Compulsory: No**			
Format	Lectures 30 h	Examples 10 h	Private study 85 h
Lecturer: E. CERVERA			

Objectives: The distribution of devices, sensors and actuators, among several mobile robots increases flexibility and robustness, and reduces the overall cost compared to monolithic solutions based on a single gifted robot. However, for efficient cooperation among a team of robots, it is necessary to address and solve challenges to efficiently manage devices and communications between them. They also represent a test for the allocation and planning of real tasks. Its applications range from exploration and / or efficient surveillance environments, to the work of rescue assistance.

Contents:

- The following subjects will be treated:
- Introduction to cooperative robotics
- Latest robotic technology network (EEE Technical Committee on "Network Robotics"
- Literature review of some significant articles in the field of cooperative robotics.
- Technology for cooperative robotics: (Zigbee, Wifi, etc..) and software (T Las Vegas, etc..),
- Architectures and software platfo cooperative robotics.
- Design of platforms for cooperative app
- Examples of these platforms can be Jad Stage, or ROS.

Practical Work: laboratory: multi-agent systems

Cognitive Processes			
Credits: 4 Semester 3 (UJI) **Compulsory: No**			
Format	Lectures 30 h	Examples 15 h	Private study 80 h
Lecturer: L. MUSEROS			

Objectives: The development of robotics has been directed toward the development of skills in robots, similar to those of human beings, regardless of the cognitive processes underlying human intelligent behavior. Probably the poor implementation of natural cognitive processes to robotics and artificial intelligence is because neuroscience, the discipline that should nurture knowledge on natural cognitive processes, has not been able so far to provide a generic explanation of behavior of our brain, which could be used for artificial intelligence and robotics. This course will approach the study of the latest discoveries in neuroscience of human brain function, and then move to the implementation of artificial cognitive processes.

Contents:

- Use of cognitive processes modeling world
- Cognitive computer vision, and sensory integration
- Construction of cognitive maps
- Cognitive processes of action
- Case study: autonomous navigation of robots
- Cognitive processes of interaction
- Modeling of artificial emotional intelligence
- Cognitive learning

Practical Work: Exercises will be set, which will involve preparing and presenting a paper in scientific format.

Ambient Intelligence			
Credits: 5 Semester 3 (UJI) **Compulsory: No**			
Format	Lectures 30 h	Tutorials 5 h, Lab.10h	Private study 80 h
Lecturer: José V. MARTÍ			

Objectives: The goal of the course is to enable students to understand the Ambient Intelligence computing paradigm, which envisions a world where people (and possibly robots) are surrounded by intelligent sensors/actuators and interfaces embedded in the everyday objects around them.

Contents:
The following subjects will be discussed:
Middleware Infrastructures for Ambient Intelligence
Networks of sensors and actuators
Robots within Smart Environments
User/Situation Modelling and Context Awareness
Human-centred adaptive interfaces, Augmented Reality and wearable computing
Applications: from Smart Dust to Smart Cities

Practical Work: Laboratory exercises with the KnowHouse simulator.

Telerobotics			
Credits: 4 Semester 3 (UJI) **Compulsory: No**			
Format	Lectures 30 h	Tutorials 5 h, Lab.10h	Private study 80 h
Lecturer: R. MARÍN			

Objectives: The overall goal of this course is to study the processes and tools to design systems of remote control for electromechanical devices. The evolution of information technologies and communications research opens new possibilities with interesting applications in improving the methods and industrial and civil processes. Device control through communication networks, and more specifically the Internet public network, is currently an emerging and very productive line of research, which also has a great interest in the industry. Still there are very few via Web robotic systems that allow remote control of electro - mechanical devices in industrial scopes and / or research. As an illustrative example, the first Internet robot (The Mercury Project) was designed and implemented in late 1995 at the University of Berkeley. Since then, the interest of the international scientific community in these systems has grown exponentially thanks in part to the very rapid evolution of features that are experiencing telecommunication and also the benefits of these remote control systems in terms of the possibility of the operator to be located anywhere in the terrestrial globe.

Contents: The following subjects will be discussed:

Networked Robots.
Telerobotics.
Tools for remote control.
Multi-Device Network Architectures.
User Interfaces for remote control.
The communication network and its influence on the remote
Applications of remote control in the social and industrial do

Practical Work: Laboratory exercises with the KnowHouse simulator.

A1.3 The third semester modules at WUT

Polish Language		
Credits: 4 Semester 3 (WUT) **Compulsory: Yes**		
Format	Lectures / Conversation: 50 h	Private study 50 h
Lecturer: WUT language department		
Objectives: Allow the student to achieve a sufficient oral and written comprehension of the local language of the hosting country. As well as an introduction to country culture. **Organization:** The language will be offered in 2 options: Beginners (joint group with 1st semester students), Advancers (for those who have a previous experience in the language); **Contents:** Culture lectures, conversations, reading, and writing exercises		

Research methodology			
Credits: 6 Semester 3 (WUT) **Compulsory: Yes**			
Format	Lectures 15 h	Seminar 10 h	Private study 120 h
Lecturers: T. Zielinska, C. Zielinski			
Objectives: This course is intended to provide the student with the necessary skills and tools to carry out and present a research topic. It presents the profession of university staff, researchers in research institutions, and in R&D departments in enterprises and how to apply for them. This course includes also the beginning of the bibliographical study and collect information part for the PhD thesis topic. **Contents:** Setting goals and defining objectives of the thesis; Bibliographical research and collect of information; Written communication: reports, theses, journal & conference papers; Oral communication: research presentations, attending conference & presenting a paper; Presentation of the profession of researchers, and university staff; The research institutions in EMARO+ countries; How to apply for a faculty position or research institutions in Europe; Seminars will be organized to present the state of art of advanced topics.			

Biomechanics			
Credits: 5 Semester 3 (WUT) **Compulsory: Yes**			
Format	Lectures 30h	Tutorials: 15 h	Private study 85 h
Lecturers: K. Kedzior, C. Rzymkowski (WUT)			
Objectives: This course presents the fundamental knowledge on the mechanics of the human body considering the skeleton and muscular system. The students will learn how to analyse static and dynamic forces and torques acting on the body parts during motion and in working conditions.			

Contents: The following subjects will be discussed:

- fundamentals of the human body anatomy,
- skeletal muscles control,
- structure, action, energy sources, power and efficiency of skeletal muscles,
- cooperation between muscles,
- biomechanics of bone tissue,
- anthropometry,
- human motion properties,
- biomechanical analysis of human motion system,
- kinematics of the human body,
- introduction to dynamical analysis of the human body,
- fundamentals of occupational biomechanics,
- medical biomechanics – prosthesis and exoskeletons,
- biomechanics of impacts/trauma biomechanics.

Practical Work:

- laboratory work, e.g EMG signals measurement and analysis;
- numerical exercises, e.g. kinematic and kinetic analysis of human gait (based on force plate and cinematographic experimental data), estimation of injury risk to the human musculo-skeletal system under impact loads;
- student presentation (~20 minutes) and preparation of a short report (~10-15 pages) on any topic (related to biomechanics), proposed by the student.

Bio-robotics

Credits: 5 Semester 3 (WUT)
Compulsory: No

Format	Lectures 30h	Project /lab. 15h	Private study 85 h

Lecturers: T. Zielinska (WUT)

Objectives:
This course presents the fundamentals of bio-inspired robotics. The topics include the biological motion properties, motion planning and biological sensors. It will be presented how the knowledge of biological motion properties is transformed into robotics. The aim of the course is to insipre creativity for novel robotic concepts by introducing recent challenges and biologicaly based solutions.

Contents: The following subjects will be discussed:

- historical background,
- motion properties of simple animals and their body build
- motion properties of complex animals and their body build,
- summary of biological motion principles
- robotics motion rules using biological inspirations,
- architectures of control systems and its reference to the neuro-biological control
- design solutions inspired by biology,
- discussion of the autonomy and adaptability observed in living world and autonomy obtained in robotics,
- humanoida, walking machines
- novel robotic systems
- guided project on biologically inspired motion synthesis of mobile robots or on the novel kinematic structures of autonomous moving robots.

Practical Work: includes project elaboration using real mobile robots or professional design software.

Dynamics of multi-body systems

Credits: 5 Semester 3 (WUT)
Compulsory: No

Format	Lectures 30h	Tutorial/project 15 h	Private study 85 h

Lecturers: J. Frączek, M. Wojtyra (WUT)

Objectives:

To learn the advanced mechanical systems dynamics and the methods of analysis of multibody mechanical systems. These systems consist of many components, thus create complex mechanisms for which classical kinematics and dynamics methods are not applicable. The gained knowledge is useful for complex systems design together with analysis of its dynamical properties.

Contents: The following subjects will be discussed:

Description of multi-body systems using different types of coordinates.
Constraints: systematic formulation of constraint equations; detection and elimination of redundant constraints.
Kinematic analysis: constraint Jacobian matrix, numerical methods used for multi-body systems analysis.
Assembling of a multi-body mechanism, detection of singular configurations.
Newton-Euler and Lagrange equations of motion for complex multi-body systems,
Direct and inverse dynamics problems for multi-body systems: formulation and methods of solving; numerical integration of ODE and DAE.
Exercises devoted to kinematics and dynamics of various mechanisms – analyses conducted using a widely used multibody package (ADAMS).

Practical Work: analysis of a given mechanical system using ADAMS package, building a simple multi-body kinematics solver in MATLAB.

Advanced mechanical design

Credits: 5 Semester 3 (WUT)
Compulsory: No

Format	Lectures 30 h	Examples/project 15 h	Private study 85 h

Lecturers: K. Mianowski (WUT)

Objectives:
This course presents the design methods for complete complex, precise mechanical structures. The students will learn how to design the mechanical structure together with mounting of actuators, driving systems, localisation of supply cables, controllers etc.

Contents: The following subjects will be treated:

Serial and parallel manipulators – difference in the requirements stated in the design
Introduction to material science,
Driving elements: their types and performances,
Analysis of mechanical efficiency in mechanical systems considering mechanical resistance (*i.e.* friction) and limited efficiency of driving system and actuators,
Actuating systems, specification of required motor power considering the designed robotics system, its mechanical efficiency and working conditions,
Design procedure using material science (material choice with material strength analysis) and including driving system, actuators, power supply, etc.
Examples considering robots for cardio-surgery, walking machines, mobile robots.

A1.3 The third semester modules at UNIGE

In UNIGE the modules are designed to give the students the necessary knowledge to carry out the master thesis in the fields of:

- Intelligent / Service / Cooperative Robotics
- Factories of the Future / Industrial Robots and Mechanical Design of New Robot Structures
- Human-Robot Interaction /Ambient Intelligence
- Perception / Manipulation

Italian Language		
Credits: 4 Semester 3 **Compulsory: Yes**		
Format	Lectures/ Conversation 50h	Private study 50 h
Lectures: UNIGE language department		
Objectives: The language courses will be offered in different levels from A1 (Beginners) to C2 according to the parameters defined in the Common European Framework of Reference for Modern Languages of European Council. Students will be evaluated in a initials tests, classes (max 25 people) will be formed according to the test results. **Contents:** Culture lectures, conversations, reading, and writing exercises		

Research Methodology			
Credits: 6 Semester 3 (UNIGE) **Compulsory: Yes**			
Format	Lectures 15 h	Seminars 10 h	Private study 120 h
Lectures: all staff			
Objectives: This course is intended to provide the student with the necessary skills and tools to carry out and present a research topic. It is considered also as the background study and collects information part for the master thesis topic, which will be completed during the fourth semester. **Contents:** It covers: Research methodology, Written communication: reports, theses, Journal & Conference papers, Oral communication: Research Presentations, Attending Conference & Presenting paper, Setting goals and defining objectives of the thesis.			

Flexible automation			
Credits: 4 Semester 3 UNIGE **Compulsory: No**			
Format	Lectures 30 h	Examples 10 h	Private study 85 h
Lecturers: M. Zoppi, D. Zlatanov			
Objectives: This course presents a general intersectorial description of the industrial automation scopes, of the involved means and methods, and of the socio-economical issues related with the domain. The scope, to be achieved, covers the definition of the scenario, into which the competencies need be enhanced with designing and developing the different topics of the industrial intelligent automation techniques. **Contents:** The following subjects will be treated: • Automation terminology. • Concepts of simultaneous engineering: product • Simulation, Virtual Manufacturing and Rapid prototyping.			

and process design.
- Mechatronics means: machines, robots, handling and transportation equipment.
- System control, process and machine diagnostics, information and communication.
- Design concepts and tools.

Practical Work: **laboratory**

- Enterprise strategies for automation and for flexibility.
- Life cycle engineering and management. Environmentally responsible manufacturing.
- Example cases will be discussed.

Advanced Modelling and Control of Robotic Structures

Credits: 4 Semester 3 UNIGE
Compulsory: Yes

Format	Lectures 24 h	Examples 16h	Private study 80 h

Lecturers: G. Casalino, M. Zoppi, M. Baglietto, A. Turetta

Objectives:
The course formerly generalizes the modelling techniques (Geometric, Kinematic and Dynamic) to robotic structures more complex than simpler cascade ones (e.g. branched, open/close and parallel connections) with extension to cases of presence of flexible links. Then it will be shown how the developed methods can be used for calibration, simulation, kinematic/dynamic/interaction control, parametric identification and adaptive control of such more general robotic structures.

Contents:
Geometric and kinematic modelling: constraints equations, mobility analysis, singularity analysis. Fundamentals of screw theory and its application to modelling, design and calibration
Dynamic modelling: principle of virtual work, Lagrangian formulations, Newton-Euler formulation.
Simulation: inverse and direct dynamic problems; use of Lagrangian formulation; use of Newton-Euler formulation; evaluation of constraints reaction force-torques.
Kinematic/dynamic/interaction control: the overall two layered functional architecture; the upper-lying kinematic control layer and relevant algorithmic structures; underlying dynamic/interaction control layer and relevant algorithmic structures, conditions for control robustness
Parametric identification: least-squ recursive techniques, Lyapunov basec within fully and partially sensorizec conditions of persistency of identifiability
Adaptive control: certainty-equivaler based techniques and Lyapunov basec
Fundamentals of Modelling and si flexible structures: flexible joints shaping; modal analysis and fini analysis, generalized Newton-Euler Identification and control aspects structures

Practical Work: Exercises will be set, involving modelling, simulation, identification and control of complex structure robots. Advanced technical papers from recent international conferences will be analysed and reviewed.

Ambient Intelligence

Credits: 4 Semester 3 (UNIGE)
Compulsory: No

Format	Lectures 30 h	Tutorials 5 h, Lab.10h	Private study 80 h

Lectures: A. Sgorbissa, F. Mastrogiovanni

Objectives:
The goal of the course is to enable students to understand the Ambient Intelligence computing paradigm, which envisions a world where people (and possibly robots) are surrounded by intelligent sensors/actuators and interfaces embedded in the everyday objects around them.

Contents: The following subjects will be discussed:
Middleware Infrastructures for Ambient Intelligence.
Networks of sensors and actuators.
Robots within Smart Environments.
Human-centred adaptive interfaces, Augmente and wearable computing.
Applications: from Smart Dust to Smart Cities.

User/Situation Modelling and Context Awareness.

Practical Work: Laboratory exercises with the KnowHouse simulator.

Distributive Robotics

Credits: 4 **Semester:** 3
Compulsory: No

Format	Lectures: 30 h	Examples: 18 h	Private study: 102 h

Lectures: G. CASALINO, A. SGORBISSA

Objectives:
Different robotic agents can be employed for achieving a set of (possibly shared) objectives via the cooperative activities. Applications of this concept ranges from the employment of teams of autonomous sensorized vehicles for distributed exploration, patrolling, monitoring, surveying, etc., to cooperating multi-mobile manipulators (each one possibly multi-arm) employed for manipulating, transporting and assembling or dismantling, large structures within constructions, rescue operations, post-disaster intervention, etc.; with a recent tendency to be proposed also for the factory or yards environments. Aspects of cooperation can be even identified within complex modular articulated chains, whenever their composing parts are viewed as a set of simpler robot agents, all together cooperating in executing the commanded tasks by part of the resulting more complex structure.
As a matter of fact the possibility for an adequate information exchange among the robot agents (either of explicit type - like cable, radio, or acoustic links -, or even of implicit type - like mutual vision and/or mutual physical interactions) and the availability of adequate (obviously distributed) cooperative control algorithms, represent the two fundamental features underlying any cooperative multi-individual-robot organization.
Accordingly with the above considerations, the main objective of the course will be that of exploiting the evidenced commonality of basic features for presenting the Cooperative robotic within an underlying unifying conceptual, methodological and algorithmic framework. In particular, while developing the framework, it will be also evidenced how the additional feature of having the each robot-agent capable of localizing itself (absolutely or ego-centrally within the team) will it also play an essential role.

Contents: The topics below will be developed with respect to ground, aerial, as well as underwater scenarios.

Robot explicit communication networks (models, technologies and algorithms) and implicit communication means (extraction of task-significant information from mutual vision and/or interaction)
Cooperative localization, mapping and navigation within multi-mobile robot agents.
Coordination control techniques for teams of autonomous vehicles.
Example applications: distributed sampling, patrolling, surveying, exploration.
Coordination control techniques for multi-mobile manipulators.
Example applications: assembly and construction, post-disaster intervention.
Modular robotic structures
Modular components and technologies
Self-configurable, self-organizing structures.
Example applications: industrial and space applications.

Machine Learning

Credits: 4 **Semester:** 3
Compulsory: No

Format	Lectures: 30 h	Tutorials: 18 h	Private study: 102 h

Lecturers: S. Rovetta, A. Verri

Objectives:
The goal of the class is to present Artificial Neural Networks and other well known Machine Learning techniques (e. g. Gaussian Processes, Bayesian Learning, hidden Markov models, etc.) as systems for solving supervised and unsupervised learning problems, with a specific emphasis on Robotics applications. Such learning systems can be applied to pattern recognition, function approximation, time-series prediction and clustering problems. Some mention will be made to the use of ANNs as static systems for information coding,

and dynamical systems for optimization and identification.

Contents: The course will cover the following topics.

- Classification and identification for contemporary versions of Rosenblatt's Perceptron, Multi-Layer Perceptrons, Support Vector Machines and other Kernel Methods, and multi-layer perceptrons.
- Approximation properties of neural networks for multilayer perceptrons and for radial basis function networks.
- Insights on Machine Learning and Statistical Learning Theory: in particular, approximation quality and generalization problems.
-
- Learning algorithms like Back-propaga Sequential Minimal Optimization t unconstrained and constrained opt problems. Practical learning examp discussed applied to Robotics.
- Neural ARMA models are derive generalization of ARMA models, a properties analysed.

Practical Work:
Exercises on the application of architectures and learning algorithms to Robotics domains.

Modular Robotics for Future Factories

Credits: 4 **Semester:** 3
Compulsory: No

Format	Lectures: 30 h	Examples: 18 h	Private study: 102 h

Lecturers: G. Cannata, (G. Casalino)

Objectives: It is currently widely recognized that a future much larger diffusion of robots for manufacturing will be achieved once the robotic research and development activities will have fully addressed the needs of SME manufacturers; which can be roughly summarized as follows: Cost effectiveness at low lot sizes, Intuitive to be used, Easily adaptable to a wide variety of application tasks, Easily reconfigurable kinematic structure, whenever needed. With the last three of the above points to be moreover operated by non-specialized personnel. In this perspective it is also recognized that a substantial answer to the mentioned needs should relay on the development of modularly configurable robotic structures, which should also exhibit motion self-organizing properties, once assembled.in the desired configuration. Still in the mentioned perspective, the present course is therefore intended for providing the students with the fundamental mechatronic concepts and related technologies enabling the the realization of reconfigurable modular robotic structures; as well as the internally distributed (within the automatically connected computational units resulting from the assembly) self-organizing control methods and related algorithms.

Contents:

- Mechanical modular technology (joints-links
- Embedded/modular actuation technology
- Embedded/modular proprioceptive sensing technology (position, velocity, joint torque sensors)
- Modular exteroceptive technologies (force/torque/tactile concentrated and distributed sensing)
- Embedded/modular processing units
- Embedded internal networking
- local joint control algorithmic units units
- Distributed self-organizing control algorithm distributed computational structures.
- Distributed internal diagnostic and fault tolera
- Self-configuring and self-assembly structures
- Foreseeable future factory application exampl
- Extension to foreseeable future space applicat