JEMARO
Erasmus Mundus Joint Master Degrees
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STUDENT HANDBOOK

ERASMUS MUNDUS JOINT MASTER DEGREES

Japan-Europe Master on Advanced Robotics: JEMARO

CENTRALE NANTES	**ECOLE CENTRALE DE NANTES**
Keio University	**KEIO UNIVERSITY**
Università di Genova	**UNIVERSITY OF GENOA**
Politechnika Warszawska	**WARSAW UNIVERSITY OF TECHNOLOGY**

Welcome!

Dear student, welcome to the Erasmus Mundus Master's JEMARO. The purpose of this handbook is to explain how JEMARO works, and what you can expect from it. The information is intended to help you find your feet and settle into postgraduate life as quickly as possible.

The handbook outlines what you can expect at each stage of your studies, the resources available, the structure and staff within the members institutions, and procedures for dealing with any problems you may encounter.

Please read this handbook carefully as it is in your interest to familiarise yourself with the regulations and procedures. Students who are uncertain about the information in this handbook should get in touch with their course coordinator. We hope you will find your time as a member of the postgraduate community rewarding and enjoyable.

1. JEMARO AT A GLANCE

The Japan-Europe Master on Advanced Robotics (JEMARO) is a 2-year integrated programme (120 ECTS or 30 Japanese Credits) between all the members of the consortium and its goal is to allow students to better understand different perspectives in Robotics and Artificial Intelligence (related to both academia and industry) across Europe (France, Italy and Poland) and Japan. This will be achieved by developing common strategies for knowledge sharing and for enforcing the quality of education in Advanced Robotics.

1.1. Partner institutions & industries

JEMARO consortium is made of 4 major Higher Education Institutions in Japan and Europe awarding master's degrees: Ecole Centrale de Nantes - ECN (France), Keio University - Keio (Japan), University of Genoa - UniGe (Italy) and Warsaw University of Technology – WUT (Poland).

In addition to these 4 main members, there are 2 other HEIs involved as Associated Partners and that may be involved in lectures, students' internships, PhD program and strategy committee: Jaume I University (Spain) and Shanghai Jiao Tong University (China).

Besides the student employability target, the JEMARO consortium also offers an innovative educational approach through the involvement of teaching staff coming from 8 industrial partners across Europe and Japan**:** YASKAWA, Soft Servo Systems, NTT Data, Motion Lib, Inc., BA Systems, PIAP-Space, PIAP, IRT Jules Verne.

1.2. Duration and mobility

The programme of study lasts two academic years (120 ECTS or 30 Japanese Credits) with the first year in Europe (ECN, UniGe or WUT) and the second in Japan (Keio University). The mobility path along with the credits' objectives are presented in Figure 1.

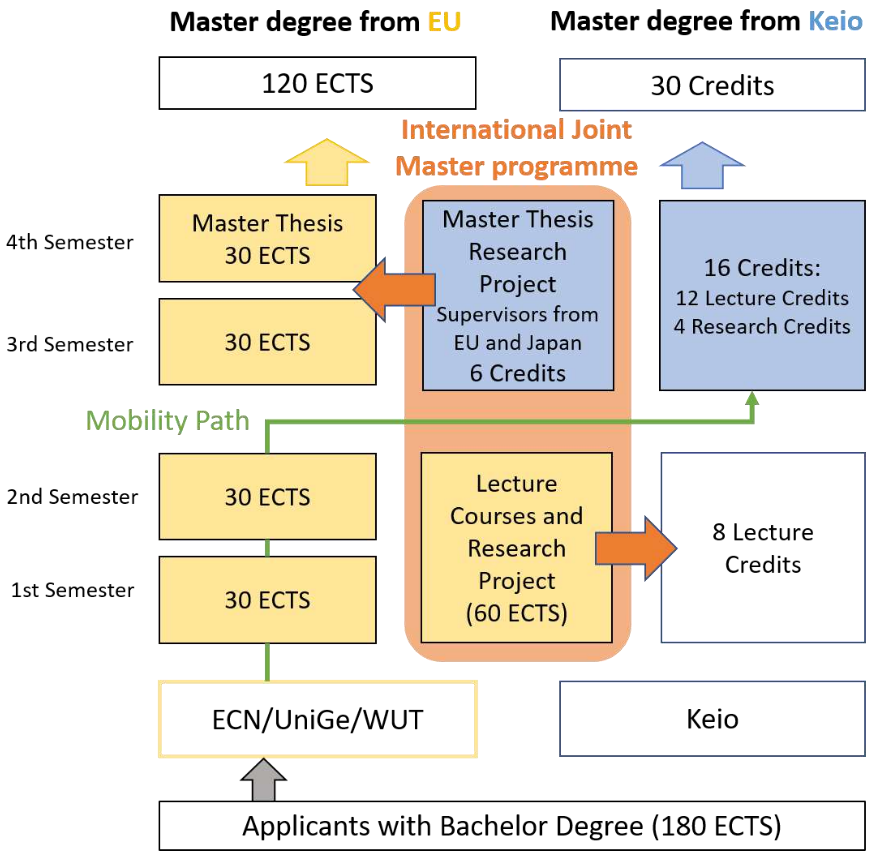

Figure 1: Student mobility path during the 2 years of master

1.3. Summary of study programme

Before starting JEMARO Master's Programme, students will have to identify a Research Topic they would like to work on for the 2 years within the so-called Research Track. Their research will be jointly supervised by a European and a Japanese professors over the 2-year programme. When applying, students are asked to rank the 3 Japanese professors they would like to work with according to mutual research interests. The co-supervisors final assignment will be decided by the end of the M1. For details, see list of Keio Professors and Research Topics here.

The aim of the first two semesters of JEMARO is to provide the students with a solid interdisciplinary background across the main areas of robotics (Mathematical Modeling, Control Engineering, Computer Engineering, Mechanical Design and Artificial Intelligence). During these two semesters, students will also conduct their own research within their Research Topic through bibliographical studies and short-term projects.

For the second year, all JEMARO students will move at Keio in Japan. During the third semester, students will follow courses related to Control, Mechatronics, Robotics, Human Interface, Signal Processing and Biological Information. The fourth semester will be mostly dedicated to the Master's

Thesis. Students carry out their research work under the joint supervision of two advisors from Europe and from Japan.

The language of instruction in JEMARO is English, but local language and culture courses of the hosting countries are included in the programme of study.

1.4. Degrees awarded

Students that graduate from the JEMARO masters' courses will obtain two masters degrees from the institutions where they studied the first and second year. The obtained degrees are officially recognised and give full access to PhD study programmes.

The Consortium will deliver Diploma supplement describing the nature, level, context, content and status of the studies that were pursued and successfully completed by the student.

1.5. Admission requirements

The Masters course applies to European and third country-students who already hold a first university degree with 180 ECTS, after at least three years of university studies (at the level of bachelor of science), in a field related to Robotics, such as: Automatic control, mechatronics, computer science, electrical engineering, mechanical engineering, and applied mathematics. The applicants have to be fluent in writing and reading in English (TOEFL (score 220 CBT, 550 PBT, 80 IBT), Cambridge Advanced English Test (score B or higher), IELTS (score 6.5 or higher), TOEIC (800).

The admission is decided on the basis of excellence of the academic records of the student, the quality of her/his former studies, motivations, reference letters and general skills for foreign languages.

2. CALENDAR

Each institution will provide to students a precise calendar key dates with dates of exams, holidays, etc. But usually, the first and third semester start on September and finish on January/February. The second and fourth semester start on February/March and finish on June/July.

3. STRUCTURE OF THE FIRST YEAR PROGRAMME IN EUROPE

3.1. Introduction

The aim of the first year is to provide the students a solid interdisciplinary background across the main areas of robotics: perception (computer vision, sensors, signal processing), cognition (computer science, artificial intelligence, human-computer interaction), action (kinematics, dynamics, control), and mathematical foundation (modelling, simulation, optimization).

The structure of the first year, M1, is shown in Table 1. It consists of two semesters, S1 (from September until January/February) and S2 (from February/March until June/July). The first semester starts with eight days of intensive local language course. The objectives, contents, assessments, etc. of all the modules are described in Annex 1.

Table 1: Structure of the first year (M1)

Host	Start of classes	First semester (30 ECTS)	Second semester (30 ECTS)
ECN	1st week of September	- Interdisciplinary background modules - Local language course	- Interdisciplinary background Modules - (Optional) Local language course[1]
UniGe	Mid-September Possibility to follow an online language course in the summer before classes start in September		
WUT	Mid-September mandatory intensive language classes followed by regular classes end of September		

3.2. Fall Semester Courses

The student will select several modules to obtain 30 ECTS[2]. Some modules like the first semester language course are compulsory. This is mentioned in the course syllabus of Annex 1.

[1] During the second semester and depending on the EU host institution, the local language course may be offered optionally without ECTS included to the required 30 ECTS quota.

[2] The minimum number of credits to validate the first semester can vary from one institution to the other

At Centrale Nantes (France), all courses are compulsory:

Courses	Lead Professors	ECTS
Research Track 1 (bibliography study)	E. HÉRY	4
Signal Processing	E. LE CARPENTIER	4
Classical Linear Control	G. LEBRET	4
Artificial Intelligence	D. MATEUS	4
Modelling of Manipulators	O. KERMORGANT	4
Advanced and Robot Programming	O. KERMORGANT	4
Mechanical Design Methods in Robotics	S. CARO	4
Modern Languages, here French as Foreign Language (compulsory)	Language Professor	2
TOTAL		30

At University of Genoa (Italy) the curriculum is a mix of compulsory and elective courses:

Courses		Lead Professors	ECTS
Research Track 1	compulsory	C. RECCHIUTO	5
Mechanics of Mechanisms and Machines	compulsory	D. ZLATANOV/M. ZOPPI	5
Modeling and Control of Manipulators	compulsory	E. SIMETTI/G.CANNATA	6
Modern Languages, here Italian as Foreign Language - brief	compulsory	Language Professor	4
Advanced and Robot Programming	elective	R. ZACCARIA	5
Artificial Intelligence for Robotics I	elective	A. TACCHELLA	5
Control of Linear Multivariable Systems	elective	G. INDIVERI	5
Real-time Operating Systems	elective	A. SGORBISSA	5
System Identification	elective	M.BAGLIETTO	5
Computer Vision	elective	F.SOLARI/N.NOCETI	5
Machine Learning for Robotics I	elective	S. ROVETTA	5
Optimisation Techniques	elective	M. SANGUINETI	5
TOTAL			30

At Warsaw University of Technology (Poland), all courses are compulsory:

Courses	Lead Professors	ECTS
Research Track 1 (Research methodology)	Professors at WUT	6
Signal Processing	W. KASPRZAK	5
Real-time Systems	T. KRUK	5
Modelling and Control of Manipulators	C. ZIELINSKI, P.TATJEWSKI	6
Computer Vision	W. KASPRZAK	5
Neural Networks	A. KORDECKI	5
Modern Languages, here *Polish as Foreign Language, introduction to Polish culture, mentoring	Language professor	4
TOTAL		36

Students can choose the optional courses from the Faculty offer (from about 30 other courses)

3.3. Spring Semester Courses

The student will select several modules to obtain 30 ECTS (the number of credits can be different from one institution to the other. Some modules are compulsory, and some have prerequisites courses from the first semester. This is mentioned in the course syllabus of Annex 1.

At Centrale Nantes (France), all courses are compulsory:

Courses	Lead Professors	ECTS
Group Project/Research Track 2	E. HÉRY	6
Optimization Techniques	A. GOLDSZTEJN	3
Mobile Robots	G. GARCIA	4
Dynamic Model Based Control	S. BRIOT/G. LEBRET	4
Artificial Intelligence for Robotics	V. FRÉMONT	4
Software Architecture for Robotics	G. GARCIA	3
Computer Vision	E. HÉRY	4
Modern Languages, here French as Foreign Language (Optional)	Language professor	2
TOTAL		30

At University of Genoa (Italy), the curriculum is a mix of compulsory and elective courses:

Courses		modelLead Professors	ECTS
Research Track 2 (compulsory)		C. RECCHIUTO	5
Human-Computer Interaction	elective	A. CAMURRI	5
Mobile Robots		G. GARCIA	5
Robot Dynamics and Control		G. CANNATA	5
Cognitive Architecture for Robotics		F. MASTROGIOVANNI	5
Embedded Systems		E. SIMETTI	5
Artificial Intelligence for Robotics II		F. MASTROGIOVANNI	5
Mechanical Design Methods in Robotics	elec tive	M. ZOPPI/P. MAIOLINO	5
Signal Processing in Robotics		M. LODI	5
TOTAL			30

At Warsaw University of Technology (Poland), all courses are compulsory (except Polish):

Courses	Lead Professors	ECTS
Research Track 2 (Group Project)	Professors at WUT	5
Mechanical Design Methods in Robotics	K. MIANOWSKI	5
Robot Programming Methods	C. ZIELINSKI	4
Mobile Robots	W. SZYNKIEWICZ	4
Artificial Intelligence	W. KASPRZAK	4
Embedded Systems	T. ZIELINSKA	4
Optimization Techniques	J. GRANAT	4
Modern Languages, here Polish as Foreign Language (Optional)	Language Professor	4
TOTAL		30

The students can choose the optional courses from the Faculty offer (from about 30 other courses).

4. STRUCTURE OF THE SECOND YEAR PROGRAMME IN JAPAN

4.1. Introduction

For the whole second year of the master's programme, all students will move to Keio University in Japan.
Locally, the programme will be split between specialized courses related to control, mechatronics, robotics, human interface, signal processing and biological information, and research activities conducted under the joint supervision of professors from EU institutions and from Keio.

Overall, the students must obtain 20 Japanese credits during their second year (M2) through the following modules:

- Independent Study (4 Japanese credits)
- Graduate Research, also known as Master Thesis (6 Japanese credits)
- 6 specialized courses (of 2 Japanese credits each, so 12 credits in total), including the mandatory course "Japanese Culture and Science/Technology"
- Japanese language courses

Local partner companies could also be involved in the courses and in the thesis supervision.

As mentioned previously, for details, see the list of Keio Professors and Research Topics here (page down to the staff section).

Examples of courses available at Keio and linked to robotics are shown in the table below. The full list of courses offered in English are proposed in Annex 2. Each course gives two (2) Lecture Credits so students have to take 7 courses. The full syllabus is available here. Compulsory Japanese language course is handles through the courses entitled "science and technology in Japanese culture".

Examples of courses proposed at KEIO	
Ultraprecision Machining and Metrology	MEMS: Design and Fabrication
Advance Course for Actuator Engineering	Space Exploration Engineering
Digital Wireless Communications	Computer Vision
Mixed Reality	Advanced Control Systems Design
Intelligent Machine System	Ad Hoc & Sensor Network
Design of Physically Grounded Communication System	Computational Structural Mechanics
Applied system design engineering	Medical Image Processing
Electromechanial Integration System	Control Engineering
Robust Control Theory	Advanced System Electronics
Science and Technology in Japanese Culture (compulsory)	

Disclaimer

The Consortium has made all reasonable efforts to ensure that the information contained within this publication is accurate and up-to-date when published but can accept no responsibility for any errors or omissions.

The Consortium reserves the right to revise, alter or discontinue modules and to amend regulations and procedures at any time, but every effort will be made to notify interested parties.

It should be noted that not every module listed in this handbook may be available every year, and changes may be made to the details of the modules.

5. ANNEX 1: SYLLABUS OF THE FIRST YEAR MODULES IN EUROPE

5.1. Syllabus of courses offered in Centrale Nantes

Research Track 1			
Credits: 4 **Fall Semester** **Compulsory: Yes**			
Format	Lectures:	Lab:	Tutorials: 32h
Lecturer: Elwan HÉRY			
Objectives: This module allows students to work in autonomy on their research topic from the first semester onwards. The aim is to produce a report in which the student develops his/her choice of research subject on which he/she will work until the end of his/her Master's degree, and proposes a first bibliographical study related to the chosen subject. The student will be in close interaction with his/her supervisors (at ECN et Keio University) for the different possible research orientations in relation to the chosen topic.			
Assessment: 100% final report			
Recommended texts and further readings: • Relevant material will be given by the teacher during the semester.			

Signal Processing			
Credits: 4 **Fall Semester** **Compulsory: Yes**			
Format	Lectures: 16h	Lab: 14h	
Lecturer: Eric LE CARPENTIER			
Objectives: • To interpret the spectral representations of signals • To understand the time sampling of signals (sample rate, anti-aliasing filter etc.) • To model a system using the transfer functions language • To model a system using the state space language • To switch from one representation to the other • To link the physical phenomena to the parameters of these representations (stability, response velocity etc.) • To simulate these mathematical representations with adapted scientific software tools (Matlab, Simulink). **Contents:** • Analysis of continuous-time and discrete-time signals • Modelling of continuous-time and discrete-time linear time invariant (LTI) systems • Design of an actual digital control implementation • Lab work			
Assessment: 30% continuous assessment, 70% final exam			

Recommended texts and further readings:

- Modern Signals and Systems, H. Kwakernaak, R. Sivan, Prentice Hall.
- Signals and Systems, R. Baraniuk, http://www.eng.ucy.ac.cy/cpitris/courses/ece623/notes/SignalsAndSystems.pdf
- Signal processing. Introduction to signals and systems theory, E. Le Carpentier, https://hippocampus.ec-nantes.fr/mod/resource/view.php?id=9179

Classical Linear Control			
Credits: 4 Fall Semester Compulsory: Yes			
Format	Lectures: 22h	Lab: 4h	Tutorials: 4h
Lecturer: Guy LEBRET			

Objectives:

- To be able to analyse the dynamic behaviour of a SISO linear system
- To be able to design a PID type controller as an example of a feedback controller
- To be able to design a feedforward controller to increase tracking performance

Contents:

- Description of SISO linear systems through the transfer function
- Analysis of behaviour (poles/zeros, first/second/more general systems, time domain/frequency domain responses etc)
- Definition the Control objectives (stability/performance, tracking/regulation)
- Nominal/robust stability (Routh, Nyquist criteria, stability margins).
- Nominal/robust performance and the unavoidable trades off between stability and performance.
- Synthesis of PID type controllers, using frequency approach tunings, in a classical closed loop (one degree of freedom controller strategy).
- Possibility of introducing a feedforward contribution which tries to “invert” the first closed loop obtained (two degrees of freedom controllers).

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- Modern Control Systems, R.C. Dorf and R.H. Bishop, Prentice Hall, 2011.
- Control Systems Engineering, N. S. Nise, John Wiley & Sons, 2011.
- Control system design, G.C. Goodwin, S.F. Graebe and M.E. Salgado, Prentice Hall, 2001.
- Multivariable Feedback Control Analysis and Design, D.S. Skogestad and I. Postlethwaite, Wiley, 2005.

Artificial Intelligence			
Credits: 4 Fall Semester Compulsory: Yes			
Format	Lectures: 16h	Lab: 12h	Tutorials: 2h
Lecturer: Diana MATEUS			

Objectives:

- To be able to use and implement graph-based strategy search, in particular using Markov decision Processes
- To be able to use and implement decision tree and artificial neural network learning (including the basics of deep learning)

- To be able to use and implement several simple flavors of reinforcement learning.

Contents:

- Basic path-finding
- Account for non-determinism
- Probabilistic outcomes
- Partial observability
- Specific problems of supervised learning and reinforcement learning

Assessment: 100% final exam

Recommended texts and further readings:

- S. Russel, P. Norvig. Artificial Intelligence: A Modern Approach (3rd ed). Pearson, 2009.

Modelling of manipulators			
Credits: 4	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 16h	Lab: 14h	
Lecturer: Olivier Kermorgant			

Objectives:

- To have a clear view of 3D geometry, including rotation parametrization and velocity screws
- To define a table of modified Denavit-Hartenberg parameters to model a robot from a sketch
- To compute (manually or with software) the direct and differential kinematic models
- To derive the inverse kinematic model for standard manipulators (6R / 3P3R)
- To understand position and velocity control modes
- To know how to generate a trajectory from a sequence of 3D waypoints
- To know various symbolic or numeric software tools that can be used to model and control Robots

Contents:

- Robot architecture, joint and operational spaces
- Homogeneous transformation matrices, 3D geometry, velocity screw
- Modified Denavit-Hartenberg parametrization and direct kinematics
- Definition and computation of the robot Jacobian
- Inverse kinematics in exact and iterative forms
- Trajectory generation
- Basic position and velocity control modes (trajectory / velocity tracking)

Assessment: 100% final exam

Recommended texts and further readings:

- Slides and labs are available online.
- W. Khalil, and E. Dombre, Modeling, identification and control of robots, Hermes Penton, 2002.
- 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.

Advanced and Robot Programming

Credits: 4	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 8h	Lab: 22h	
Lecturer: Olivier KERMORGANT			

Objectives:

To give the students the fundamentals of:

- Modern programming (with C++)
- Industrial robot manipulator programming with specialized robot languages

Contents:

C++:

- Basic types, STL useful classes (string, vector, pair, map), struct
- Control blocks: if/then/else, for, while, switch
- Functions: argument passing, overloading
- Classes: attributes and methods, inheritance
- Templates, lambda-functions and STL algorithms
- Code organization
- Compilation with Cmake, using external libraries
- Debugger and profiler

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,
- Real-time aspects of robot programming,
- The V+ language, including its real-time aspects and sensor-handling capabilities.

Assessment: continuous assessment 50%, final exam 50%

Recommended texts and further readings:

- C. Blume, W. Jakob, Programming Languages for Industrial Robots, Springer Verlag.
- Stäubli: RX Robots Technical Documentation, 2001.
- Bruce Eckel, Thinking in C++, volumes 1 and 2, 2007.

Mechanical Design Methods in Robotics

Credits: 4	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 18h	Lab: 12h	
Lecturer: Stéphane CARO			

Objectives:

- To design serial and parallel robotic manipulators.
- To correctly formulate the information required for conceptual design (requirements),
- To use CAD systems on the basic level for the design of a typical mechanism (serial arm),
- To elaborate the design on general level without consideration of material, drive systems and actuators,
- To generate manufacturing drawings.

Contents:

• 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 aided design, use of CAD software. • The design of robotic production cells. • Fundamentals of integrated design of control and drive systems taking into account measurement, gearing and transmission systems.
Assessment: Final exam and final project
Recommended texts and further readings: • French, M. J. Conceptual Design for Engineers, 3rd ed., 1999 (Springer) • Pahl, G. and Beitz, W. Engineering Design: A Systematic Approach, 2nd ed. Wallace, K.M. • (editor); Blessing, L., Bauert, F. and Wallace, K.M. (translators), 1996 (Springer-Verlag, London) • Suh, N.P. The Principles of Design, 1990 (Oxford University Press, Oxford) • Suh, N.P. Axiomatic Design. Advances and Applications, 2001 (Oxford University Press, Oxford) • Kong X. and Gosselin, C., Type Synthesis of Parallel Mechanisms, Springer Tracts in Advanced Robotics, 2007.

Group project/Research Track 2			
Credits: 6	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 0h	Lab: 0h	Project: 32h
Lecturer: Elwan HÉRY and professors at ECN			
Objectives: • To contribute to solving a scientific, technological or theoretical problem proposed by any of the instructors of the master (professors, assistant professors, researchers etc.) or industrial partners. **Contents:** • The students (individually or often a group of two) organize the project. Depending on the subject, a bibliography may be necessary, an original methodology or solution can be proposed or it can involve purely the application of techniques learned throughout the courses. • 32 hours are set aside for the project in the timetable, but additional personal work will be required. Project assessment is based on a written report and an oral presentation.			
Assessment: written report and oral presentation (100%)			
Recommended texts and further readings: • Relevant material will be given by the teacher during lectures.			

Optimization techniques			
Credits: 3	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 14h	Lab: 16h	
Lecturer: A. GOLDSZTEJN			
Objectives: • To acquire the ability to formalise, select the appropriate method, implement the optimisation problem and then analyse the results in order to take the best decision			

regarding the objectives, variables and constraints

Contents:

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

Assessment: continuous assessment 50%, final exam 50%

Recommended texts and further readings:

- R. Fletcher, Practical Methods of Optimization, Wiley, 2000.
- Mitchell Melanie: An Introduction to Genetic Algorithms, MIT Press 1996

Mobile Robots			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 20h	Lab: 10h	
Lecturer: Gaëtan GARCIA			

Objectives:

- To provide students with the necessary tools to model, localize and control conventional wheeled mobile robot

Contents:

- Modelling of wheeled Robots: Constraint equations, Classification of robots using degrees of mobility and steerability, Posture kinematic model, Configuration kinematic model, Motorisation of wheels.
- Localization: Relative localization using odometry, Absolute localisation, Localization sensors, Localization using extended Kalman filtering.
- Control: Controllability and stabilization, static and dynamic feedback linearization, nonlinear control based on Lyapunov functions.
- Practical Work: The students will study various control laws in simulation. They will also implement a Kalman filter-based localization algorithm using data recorded with a real robot.

Assessment: continuous assessment 30%, final exam 70%

Recommended texts and further readings:

- "Theory of robot control", Carlos Canudas de Wit, Bruno Siciliano, Georges Bastin, Springer Science & Business Media, 2012 - 392 pages.
- PDF documents provided by the teachers.

Dynamic Model Based Control			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 22h	Lab: 4h	Tutorials: 4h

Lecturer: Sébastien BRIOT / Guy LEBRET
Objectives: • To present a unified methodology to obtain control laws. • To explore different formalisms for the computation of the dynamic model will be explored (Newton-Euler, Lagrange equations). **Contents:** • State space approach of linear multivariable systems (Time domain state response, modal decomposition of the response, controllability, observability…) • Mechanisms or more specifically, serial robots (tecalls of classical mechanics, Newton-Euler equations, Euler-Lagrange equations, optimal computation of dynamic models for serial robots)
Assessment: continuous assessment 30%, final exam 70%
Recommended texts and further readings: • "Control system design", G.C. Goodwin, S.F. Graebe and M.E. Salgado, Prentice Hall, 2001. Page 21 of 24 • "Linear Multivariable Control, A Geometric Approach", W.M.Wonham. Springer Verlag, New York, 1985. "Linear Systems", T. Kailath, Prentice-Hall, New Jersey, 1980. • "Modelling, Identification and Control of Robots" W. Khalil and E. Dombre, Hermes Penton, Ltd, 2002

Artificial Intelligence for Robotics			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 20h	Lab: 10h	
Lecturer: Vincent FRÉMONT			
Objectives: This course aims to present recent artificial intelligence techniques for robotics. **Contents:** • Applied Math and optimization technics for Machine Learning • Convolutional Networks • Semantic Segmentation • Object Detection • Place recognition for SLAM • Belief Functions Theory: application to Evidential Occupancy Grids for autonomous vehicles • Hardware and GPU processing for Deep Learning • Deep Learning Frameworks Practical Sessions: • Lab1: Object detection using Deep Learning • Lab2: Reinforcement Learning • Lab3: Deep Reinforcement Learning			
Assessment: continuous assessment 30%, final exam 70%			
Recommended texts and further readings: • Deep Learning by Ian Goodfellow, Yoshua Bengio, Aaron Courville. • Artificial Intelligence for Robotics: Build intelligent robots that perform human tasks using AI techniques, Francis X. Govers, 2018.			

• Course by Andrea Vedaldi: http://www.robots.ox.ac.uk/~vedaldi/teach.html • Ethics of Artificial Intelligence and Robotics: https://plato.stanford.edu/entries/ethics-ai/
Prerequisites: Artificial Intelligence course from S1

Software Architecture for Robotics			
Credits: 3 **Spring Semester** **Compulsory: Yes**			
Format	Lectures: 12h	Lab: 18h	
Lecturer: Gaëtan GARCIA			
Objectives: • To define which sensory information is needed and how it must be processed; • To couple sensory information and internal representation structures, which must be appropriate in terms of efficiency, computational load and usability; • To design and develop algorithms to operate on such representation structures; • To embed those algorithms in software modules and components, which must be concurrently executed on (typically real-time) operating systems. **Contents:** • Design patterns for robot software development, • Component-based software engineering aspects, • Typologies of software architecture for robots, and their use in real-world scenarios, • Biologically-inspired approaches to robot software design, • Real-time and non-real-time software components, • Integration of robot perception, knowledge representation, reasoning, and action. • Practical introduction to ROS in the labs.			
Assessment: continuous assessment 50%, final exam 50%			
Recommended texts and further readings: • Relevant material will be given by the teacher during lectures.			

Computer Vision			
Credits: 4 **Spring Semester** **Compulsory: Yes**			
Format	Lectures: 20h	Lab: 10h	
Lecturer: Elwan HÉRY			
Objectives: • To acquire knowledge and skills in computer vision and image processing to understand and to master methods for artificial perception and scene understanding. • To learn to implement current visual odometry pipelines used in mobile robots and to understand the basic principles of Deep Learning algorithms for robotic applications. **Contents:** • Introduction • Image Formation 1: perspective projection and camera models • Image Formation 2: camera calibration algorithms • Filtering and Edge detection			

- Feature Point Detection
- Multiple-view Geometry and Robust Estimation
- Optical Flow and Feature Tracking
- Visual SLAM Frameworks
- Deep Learning for robotics and Semantic Segmentation

Assessment: Lab assessment 50%, final exam 50%

Recommended texts and further readings:

Recommended textbooks:

- Digital Image Processing, by Rafael C. Gonzalez and Richard E. Woods, 2018
- Computer Vision: Algorithms and Applications, by Richard Szeliski, 2009.
- Multiple view Geometry, by R. Hartley and A. Zisserman, 2003.
- An Invitation to 3D Vision, by Y. Ma, S. Soatto, J. Kosecka, S.S. Sastry, 2004.
- Robotics, Vision and Control: Fundamental Algorithms, by Peter Corke, 2011.

Online courses:

- Course by Davide Scaramuzza: http://rpg.ifi.uzh.ch/teaching.html
- Course by James Hays at Brown University: https://www.cc.gatech.edu/~hays/
- Course by Andrea Vedaldi: http://www.robots.ox.ac.uk/~vedaldi/teach.html

5.2. Syllabus of the courses offered at University of Genoa

Research Track 1		
Credits: 5	**Fall Semester**	**Compulsory: Yes**
Format	Lectures: 25h	Lab: -

Lecturer: Carmine RECCHIUTO

Objectives:

- To learn basic aspects of software programming for robotics;
- To know and use the robotic framework ROS;
- develop simple software architecture based on different communication paradigms (publish/subscribe, client/service);
- implement and modify simple simulations involving mobile robots

Contents:

- Linux (for Robotics)
- Python (for Robotics)
- C++ (for Robotics)
- Docker
- Distributed Version Control Systems
- Basic principles of ROS
- Services and messages in ROS
- Simulation of Mobile Robots with ROS and Gazebo

Assessment: During the course, students will have to implement two assignments, based on the contents of the course.The final exam will consist of practical exercises. The final evaluation will be composed of the evaluation of the assignments (30%) and the evaluation of the final practical exam (70%).

Recommended texts and further readings:

- All slides shown during the lessons and other teaching materials will be available on the Aulaweb platform. Generally speaking, notes taken during the lessons and teaching materials uploaded on Aulaweb will be sufficient for the course.

Mechanics of Mechanisms and Machines		
Credits: 5	**Fall Semester**	**Compulsory: Yes**
Format	Lectures: 40h	Lab: -

Lecturers: Dimiter ZLATANOV and Matteo ZOPPI

Objectives:

The course will introduce students to modern mathematical methods of modelling rigid-body motion as applied to the study, design, and control of robotic mechanisms. The focus will be on the geometry, kinematics, and statics of articulated multi-body systems, with targeted applications in mechanism analysis and synthesis, as well as robot dynamics, flexibility, and control.

Contents:

- Linear spaces, screws, twists, and wrenches: the basics of screw theory.
- Application: constraint analysis and synthesis of parallel manipulators.
- Kinematic geometry of planar mechanisms.
- Velocity and singularity analysis.

• Statics of mechanisms.
Assessment: Final exam. Written exam or alternatively an oral interview based on the number of students per session.
Recommended texts and further readings: • Hunt, K., 1978, Kinematic geometry of mechanisms, Clarendon Press. • Murray, R.M, Li, Z., and Sastry, S.S., 1994, Mathematical introduction to robotic manipulation, CRC. • John Joseph Uicker, J.J., G. R. Pennock, G.R., and Shigley, J.E., 2016, Theory of Machines and Mechanisms. 5th ed. New York: Oxford University Press.

Modeling and Control of Manipulators			
Credits: 6	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 48h	Lab: -	
Lecturers: Enrico SIMETTI, Giorgio CANNATA			

Objectives:

This course presents the fundamentals of the kinematics modeling and control techniques of serial manipulators. Topics include geometric modeling, task jacobian matrices, inverse kinematics, and closed loop kinematics control. At the end of the course, the student will be able to:

- describe the relationships between frames in the environment using the mathematical tools such as rotation matrices or homogeneous transformations
- create the geometric model of a manipulator
- understand the kinematics of points and frames in space, with respect to different observers
- derive the kinematic equations that describe how a part of the robot moves as a function of the joints velocities (Jacobian relationship)
- implement a closed loop control system to achieve certain prescribed objectives in the operational space

Contents:

- General geometric fundamentals
- The Geometric Model of a Robot
- General Kinematic fundamentals
- Robot kinematics: Basic Jacobian matrices; Task Jacobian matrices; the Inverse Kinematic problem.
- Closed-loop Inverse-Kinematic based control (CLIK); Task-Priority based CLIK (TP-CLIK);

Assessment: 30% continuous assessment, 70% final exam (Oral colloquium, with the possibility of developing some simple exercises on manipulator control problems)

Recommended texts and further readings:

- B. Siciliano, L. Sciavicco, L. Villani, L. Oriolo: "Robotics: Modelling, Planning and Control"; Mc Graw-Hill, 2009
- W. Khalil, and E. Dombre, "Modeling, identification and control of robots", Hermes Penton, London, 2002

  Further readings:
- J. Angeles, Fundamentals of Robotic Mechanical Systems, Springer-Verlag, New York, 2002

Advanced and Robot Programming			
Credits: 5 **Fall Semester** **Compulsory: No**			
Format	Lectures: 40h	Lab: -	
Lecturer: Renato ZACCARIA			

Objectives:
Following the Bloom's taxonomy, the student will achieve the following results (levels 2 to 4):
- Describe the behavior of the different communication / synchronization primitives between tasks and processes (events, shared memory, messages) both in a single and in networked machines.
- Apply state-of-practice concurrent / distribute programming schemes to solve reference problems in robotics.
- Compare different communication / synchronization primitives in solving common robotic problems, and
- Motivate the selection of the most suitable for a specific process.
- Design and test concurrent / distributed programmes to solve standard, complex, relevant cases in robotics.

Contents :
1. Course intro
2. Op sys architecture 1
3. Op sys architecture 2
4. SysCalls1: processes
5. SysCalls2: threads
6. SysCalls3: mutual exclusion, synchronization
7. SysCalls4: pipes
8. SysCalls5: non determinism
9. SysCalls6: events
10. SysCalls7: sockets
11. Publish/Subscribe: D-BUS
12. Real cases analysis

Assessment: The final exam is only one othe component of the assessment process. The exam mark will contribute approximatively with 22% - 33% of the full assessment.
The exam consists in an on line test on the AulaWeb portal, with questions related to the learning outcomes. The test is done in presence in the classroom.

Recommended texts and further readings:
- Relevant material will be given by the teacher during lectures.

Artificial Intelligence for Robotics I			
Credits: 5 **Fall Semester** **Compulsory: No**			
Format	Lectures: 40h	Lab: -	
Lecturer: Armando TACCHELLA			

Objectives:

The course introduces the languages and the techniques through which intelligent agents can operate autonomously on a deductive basis. The aim of the course is to provide students with the capability of formalizing domains of interest in order to treat them in the context of autonomous intelligent agents, with specific reference to propositional logics, first-order logics, description logics, and automated planning languages. The main result is the student's ability to frame the problems in a formal way and abstract their main features in a specification which makes computationally feasible to implement autonomous agents

Contents:

- Propositional logic: syntax, semantics, propositional knowledge bases, normal forms, inference procedures.
- First-Order Logic: representation, syntax and semantics, knowledge engineering, inference procedures.
- Classical Planning: definition, PDDL language, examples, planning as state-space search.

Assessment: Test with open and closed questions

Recommended texts and further readings:

- Stuart Russell, Peter Norvig - Artificial Intelligence, a Modern Approach (third edition) - Prentice Hall

Control of Linear Multi-variable Systems

Credits: 5	Fall Semester	Compulsory: No	
Format	Lectures: 40h	Lab: -	

Lecturer: Giovani INDIVERI

Objectives:

At the end of the course, the students will be able to:

a) Build and analyze linear time-invariant multivariable system models.
b) Solve basic control allocation problems building on matrix pseudo inverse methods.
c) Design regulators capable of ensuring a certain closed-loop dynamics, even in the case in which the state of the system is not fully accessible.

Contents:

- Basics on modeling and analysis of linear multivariable systems (continuous and discrete);
- Stability and structural properties of linear multivariable dynamic systems;
- Matrix pseudo inversion methods for control allocation, inverse kinematics and motion control within robotics applications;
- Pole assignment and state observers for linear multivariable time invariant dynamic systems.

Assessment: oral exam. The students will be evaluated on the basis of their capability to solve simple analysis and control problems.

Recommended texts and further readings:

- H. Kwakernaak, R. Sivan - Linear Optimal Control Systems - Wiley 1972
- Papers and notes distributed by the lecturer;

Real-time Operating Systems

Credits: 5	Fall Semester	Compulsory: No	
Format	Lectures: 14h	Lab: 18h	

Lecturer: Antonio SGORBISSA

Objectives:

- To understand problems related to real-time applications and operating systems;
- To understand how to use real-time operating systems following the Posix standard and Linux-RTAI
- To expand the acquired knowledge to understand how to use additional real-time operating systems that have not been presented in the class;
- To apply the acquired knowledge to solve problems, in particular for the design of real-time applications;
- To analyse the characteristics of state-of-the-art real-time operating systems and categorize them on the basis of such characteristics.

Contents:

- Real-time operating systems:
  - Basic principles;
  - Scheduling algorithms for periodic tasks: Rate Monotonic, Earliest Deadline First, Deadline Monotonic;
  - Scheduling algorithms for aperiodic tasks: schedulazione in background, Polling Server, Deferrable Server;
  - Protocols for access to shared resources: Priority Inheritance, Priority Ceiling;
  - Rate Monotonic on a CAN bus.
- Soft real-time systems (Posix):
  - thread, mutex and conditional variables;
  - Rate Monotonic;
  - Background scheduling and periodic servers;
  - Interprocess communication;
- Linux Device Drivers;
  - System calls;
  - User and kernel space;
  - I/O and interrupt programming;
  - Case study: a driver for the parallel port.
- Hard real-time systems:
  - QnX, VxWorks, Windows CE;
  - RTAI: periodic and aperiodic tasks, communication mechanisms.

Assessment: The exam is written and requires the student to solve problems related to the design of a real-time system using the theoretical and practical tools seen during the year. The exam requires that the student is able to design, using theoretical bases and practical tools presented during lectures and during exercises, a real-time application with given characteristics.

Recommended texts and further readings:

- Buttazzo, Giorgio C. Hard Real-time Computing Systems, Kluwer Academic publishers, 1997
- Alessandro Rubini and Jonathan Corbet, Linux Device Drivers, Third Edition, O'Reilly and Associates, June, 2001 (available online at http://oreilly.com/openbook/linuxdrive3/book/)
- Tom Wagner and Don Towsley, Getting Started With POSIX Threads (available online)
- https://www.rtai.org/

System Identification			
Credits: 5	**Fall Semester**	**Compulsory: No**	
Format	Lectures: 40 h	Lab: -	
Lecturer: Marco BAGLIETTO			

Objectives: The goal of the course is to provide methodologies and tools for designing systems' models to be used for control, estimation, diagnosis, prediction, etc. Different identification methods are considered, both in a "black box" context (where the structure of the system is unknown), as well as in a "grey box" (uncertainty on parameters) one. Methods are provided for choosing the complexity of the models, for determining the values of their parameters, and to validate them. Moreover, state estimation problems are addressed and their connections with control and identification are considered.

Contents:

Different models for dynamic systems and their applications.

- Parametric and non-parametric models
- Identification techniques for linear models
- Nonlinear models. Examples and identification methods.
- Validation procedures.
- Introduction to state estimation.
- State estimation in the presence of disturbances.
- Kalman filter and its extension to the nonlinear case.
- Techniques for parameter identification of linear systems in the presence of disturbances.

Assessment: Oral exam with discussion of system identification and state estimation methods and possible applications.

Recommended texts and further readings:

- L. Ljung, "System Identification: Theory for the User", Prentice Hall
- Y. Bar-Shalom, X. R. Li, T. Kirubarajan, "Estimation with Applications to Tracking and Navigation", John Wiley & Sons
- Further readings will be given by lecturer

Computer Vision			
Credits: 5	**Fall Semester**	**Compulsory: No**	
Format	Lectures: 40h	Lab: -	
Lecturers: Fabio SOLARI and Nicoletta NOCETI			

Objectives:

The aim of the course is to provide a broad introduction to different core aspects of computer vision, including camera modelling, camera calibration, image processing, pose estimation, multi view geometry, visual tracking, and vision based calibration. At the end of the course the student will be able to understand the main theoretical concepts and to design and implement classical computer vision algorithms. The course will also provide an overview of the main application domains, with a special reference to the robotics scenario.

Contents:

- Introduction to computer vision for robotics applications
- Part 1 - image processing fundamentals
  - Digital image fundamentals: sensing and acquisition, sampling and quantization, basic

operations (warping) - Intensity transformations and spatial filtering (filtering in the frequency domain) - Edge and corner detection - Color image processing - Hough transforms and image segmentation - Scale space and blob detection - Image matching • Part 2 - motion analysis - Motion: 3D and 2D motion fields, dense and sparse optical flow. Dominant motion estimation - Tracking with linear dynamic models (Kalman Filter) • Part 3 - geometry - 3D computer vision fundamentals - The geometry of image formation: review of projective geometry (basic), projective transformations, camera models and single view geometry, camera calibration, Homographie - Stereopsis: epipolar geometry, stereo rectification, depth estimation, 3D reconstruction • Conclusions: Visual Recognition and image retrieval; introduction to object and action recognition methods in HRI
Assessment: 50% from a continuous assessment through practical laboratory exercises done throughout the semester. 50% from the end-semester exam, organised as follows: • A multiple-choice quiz (~5%) that is a threshold for attending the oral exam; • An oral exam (~45%). It is not allowed to consult books, notes, or other written material.
Recommended texts and further readings: • R.C. Gonzalez and R.E. Woods, Digital image processing, Prentice-Hall, 2008. • E. Trucco and A. Verri, Introductory Techniques for 3-D Computer Vision, Prentice Hall, 1998. • Further readings: Material distributed by lecturers through the Aulaweb portal

Machine Learning for Robotics I			
Credits: 5 **Fall Semester** **Compulsory: No**			
Format	Lectures: 40h	Lab: -	
Lecturer: Stefano ROVETTA			
Objectives: After successfully attending the course, the student will be able to: • demonstrate knowledge of a range of techniques and problems in machine learning and pattern recognition, including the underlying scientific and technical rationale • apply selected techniques to relevant problems • code simple and medium-complexity machine learning methods using standard programming tools, without being limited to using software libraries • tackle the workflow of a machine learning assignment from data wrangling to result presentation			

- use critical thinking to analyse a problem and select the appropriate machine learning method to apply

Contents:

- Introduction
- Perceptual problems
- The decision problem in the presence of complete deterministic information: Representation problems
- The decision problem in the presence of complete probabilistic information: Bayes decision theory
- The decision problem in the presence of incomplete samples (data): Statistics and the learning problem. Inductive bias, the bias-variance dilemma
- Parametric methods and maximum likelihood estimation
- Non-parametric methods, some popular classification and clustering methods
- Evaluating learning: Indexes and resampling methods.
- Neural networks: Historical methods, shallow networks
- The learning problem as optimization. Algorithms and strategies.
- Data mapping: Dimensionality reduction and kernel methods
- Deep neural networks
- Learning from sequential data

1. **Assessment:** The final exam consists in an interview with technical questions and exercises, and in the discussion of the assignments. Final marks given 50% by continuous assessment and 50% by exam.

Recommended texts and further readings:

Course slides and assignments are available on the official study portal. A selection of suggested readings (journal articles and textbooks) will be provided during lectures.

Optimisation Techniques			
Credits: 5	**Fall Semester**	**Compulsory: No**	
Format	Lectures: 40 h	Lab: -	
Lecturer: Marcello SANGUINETI			

Objectives:

The Course aims at providing the students with the skills required to deal with engineering problems, with particular emphasis on Robotics Engineering, by developing models and methods that work efficiently in the presence of limited resources.

The students will be taught to: interpret and shape a decision-making process in terms of an optimization problem, identifying the decision-making variables, the cost function to minimize (or the figure of merit to maximize), and the constraints; framing the problem within the range of problems considered "canonical" (linear / nonlinear, discrete / continuous, deterministic / stochastic, static / dynamic, etc.); realizing the "matching" between the solving algorithm (to choose from existing or to be designed) and an appropriate processing software support

Contents:

- Introduction. Optimization and Operations Research for Robotics. Optimization models and methods.

- Linear programming model and algorithms
- Integer linear programming model and algorithm
- Nonlinear programming model and algorithms
- Graph optimization models and algorithms
- N-stage optimization: dynamic programming model and algorithms
- Putting things together: models, methods, and algorithms for the optimisation of robotic systems
- Software tools for optimization
- Case studies from Robotics

Assessment:
Written. Exercises and questions on the applications illustrated and the main concepts explained during the lectures. Comprehension of the concepts explained during the Course. Capability to:

- interpret and shape a decision-making process in terms of an optimization problem, with particular attention to decision problems in Robotics;
- frame the problem in the range of problems considered "canonical" (linear / nonlinear, discrete / continuous, deterministic / stochastic, static / dynamic, etc.);
- choose and/or develop a solution algorithm that implements a suitable optimization technique, with particular attention to problems arising in Robotics.

Recommended texts and further readings: Lecture notes provided by the teacher (study material will be available in the official study portal).

Research Track 2			
Credits: 5	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 25h	Lab: -	
Lecturer: Carmine RECCHIUTO			

Objectives:

- - create some effective visuals for showing data
- - use notebooks for controlling and managing robotic simulations
- - write proper documentation for the developed code
- - define a research hypothesi
- - use the correct statistical instruments for validating their hypotheses
- - search scientific resources
- - perform a literature analysis
- - communicate effectively in written and oral form, adapting their communication to the context, using sources and aids of various kinds
- - develop critical thinking, argumentative skills, and the ability to use, process and evaluate information

Contents:

The course program consists of the following topics:

- - Data visualization and Matplotlib
- - Jupyter Notebook
- - Software Documentation, Doxygen and Sphinx

- - Statistical tools for robotics engineering
- Elements of Research Methodology

Assessment:

During the course, students will have to implement an assignment, which will start from the final assignment of Research Track I.

During the final exam the student will discuss his/her Research Line (ie a bibliographic analysis on a defined theme) carried out during the course. Students are also required to write a report on their line of research.

The final evaluation will consist of the evaluation of the assignment (40%) and the evaluation of the work done for the research line (discussion + report, 60%).

Recommended texts and further readings:

- All slides shown during the lessons and other teaching materials will be available on the Aulaweb platform. Generally speaking, notes taken during the lessons and teaching materials uploaded on Aulaweb will be sufficient for the course.

Human Computer Interaction			
Credits: 5	**Spring Semester**	**Compulsory: No**	
Format	Lectures: 40h	Lab: -	

Lecturer: Antonio CAMURRI

Objectives:

Acquisition of concrete skills in the Interaction Design (ID) development process for multimedia and multimodal interfaces: how to manage the development process (Iterative, User-Centered, Participatory Design); usability, user experience, and evaluation in HCI/ID. Basic introductory knowledge on the design of emotional and social interfaces, and on sound and music computing.

Contents:

- Introduction to Human Computer Interaction and Interaction Design (ID). The ACM curricula on HCI.
- Foundations of human perception and cognition for human-centred interactive systems. Usability and User experience.
- Interfaces: command-based, WIMP and GUI, Virtual reality, Mobiles, Multimedia, Speech, Touch, Air-based gesture, Motion Capture, Haptic, Shareable, Tangible, Wearable, AR/MR, Multimodal.
- Designing, developing, and evaluating interfaces: the ID development process.
- Design Principles – Usability: learnability, visibility, errors, efficiency.
- Design Techniques: Task, User, Domain Analysis, Prototyping, User testing;
- Theories and models supporting the development process.
- Evaluation and research methods:
- Experiment design; Controlled experiments; Statistical techniques for the analysis of interfaces (foundations).

Assessment: The exam consists of two parts:

1- Practical project: developed during the whole semester in class and with assignments.
2- Written exam, followed by oral exam.
At the end of the course, usually the last lesson, a simulation of an example of a written exam will be presented and discussed.

Recommended texts and further readings:

- Course slides and suggested readings available online from AulaWeb page of the course (MS in Ingegneria Informatica);
- Preece, Rogers, Sharp (2015) "Interaction Design – Beyond Human-Computer Interaction", Wiley, 4th Ed. Slides available online at http://www.id-book.com/slides_index.php

Mobile Robots			
Credits: 5	**Spring Semester**	**Compulsory: No**	
Format	Lectures: 40h	Lab: -	
Lecturer: Gaëtan GARCIA			

Objectives:

- The students will be able to tackle real problems in mobile robotics. In kinematic modeling and in localization, their experience will involve practical knowledge and, in localization, hands on experience with real data

Contents:

- Modelling of wheeled Robots: Constraint equations, Classification of robots using degrees of mobility and steerability, Posture kinematic model, Configuration kinematic model, Motorisation of wheels.
- Localization: Relative localization using odometry, Absolute localisation, Localization sensors, Localization using extended Kalman filtering.
- Control: Controllability and stabilization, static and dynamic feedback linearization, nonlinear control based on Lyapunov functions.
- Practical Work: The students will study various control laws in simulation. They will also implement a Kalman filter-based localization algorithm using data recorded with a real robot.

Assessment: The exam is based on exercises that remain fairly close to class examples and homework examples. The exam typically is a mix of questions that must be solved by calculation, and questions that must not. The exam also contains questions that are meant to evaluate the knowledge gained from the labs.

Recommended texts and further readings:

- "Theory of robot control", Carlos Canudas de Wit, Bruno Siciliano, Georges Bastin, Springer Science & Business Media, 2012 - 392 pages.
- PDF documents provided by the teachers.

Robot Dynamics and Control			
Credits: 5	**Spring Semester**	**Compulsory: No**	
Format	Lectures: 40h	Lab: -	
Lecturer: Giorgio CANNATA			

Objectives: The course introduces the dynamic modelling of robot manipulators and the fundamentals of dynamic control of robots. These aspects are the key elements for the design of robot controllers and for the implementation of robot-controlled operations involving interaction of the robot with objects (e.g. for their manipulation), the environoment (e.g. force control), humans (e.g. human robot collaborative tasks).

Contents:

- Introduction
- Vector computation
- Elements of kinematics and dynamics
- Rigid body dynamics
- Statics and dynamics of kinematic chains
- Computational Robotics
- The control problems
- Dynamic robot control methods
- Examples

Assessment:

Final grades will be based on assignments.

Written + oral exams are also possible, but not encouraged since the outcome of the course is to give operational capabilities for the design of new robot systems.

Recommended texts and further readings:

- Lecture notes
- Text books: none suggested (since there are many very good around but using different notations)
- Suggested reading:
- Fundamentals of Robotic Mechanical Systems. J. Angeles
- Robotics. Modelling, planning, and control. B. Siciliano et al.

Cognitive Architecture for Robotics			
Credits: 5	**Spring Semester**	**Compulsory: No**	
Format	Lectures: 40h	Lab: -	
Lecturer: Fulvio MASTROGIOVANNI			

Objectives: The main objective of Cognitive Architectures for Robotics (COGAR) is to provide students, scholars, and future researchers with advanced concepts and methodological tools about how to design advanced forms of intelligence embodied in robots and in the way they interact with the environments, the objects therein, and humans.

Robots are quickly becoming complex systems made up of modules and components whose behavior is complex in its own right, that is, not all the consequences of certain design choices can be easily predicted in advance to guarantee the overall robot behavior. The study and the synthesis of advanced forms of cognition and intelligence in robots requires:

- defining which sensory information is needed, how it can be be processed, and how it can be integrated to form actionable information;
- coupling sensory information and internal structures to represent information, in forms appropriate in terms of data recollection, integration, and synthesis of new knowledge;
- designing algorithms to reason on such representation structures, for example to perform deduction, induction, or abduction of facts;
- embedding knowledge representation structures and algorithms in software architectures designed to mimick advanced cognition capabilities, which may be inspired by those found in higher mammals or cephalopods, or based on completely different assumptions.

CogAR will provide a reasoned treatment of advanced concepts in cognition, state-of-the-art design approaches, and advanced research trends in this field, as well as a comprehensive discussion about typical scenarios, solutions, and use cases. **Contents**: Each year, the COGAR team updates the subject given new trends and development in cognitive robotics. This means that the subject is slightly different each year. COGAR introduces theoretical concepts and integrates them with practical insights. Examples and use cases are implemented using the widely adopted ROS framework. COGAR is based on the following macro-topics. TOPIC 1: Introduction and motivations: 1/ Introduction to the course: what to expect, organization, exam. 2/ Cognition in humans and robots. TOPIC 2: From software architectures to robot cognitive architectures: 1/ How we describe cognitive architectures: the Unified Modelling Language. 2/ Design patterns in Robotics for behavior-based robots, autonomous robots, and human-robot interaction. Practice classes focused on TOPIC 2. TOPIC 3: Classical robot architectures (with examples): 1/ Sense-Plan-Act architectures. 2/ Behavior-based architectures. 3/ Hybrid reactive-deliberative architectures. Practice classes focused on TOPIC 3. TOPIC 4: Cognitive architectures: 1/ Knowledge representation and reasoning techniques. 2/ Memory models, learning, and adaptation. 3/ Integrated task and motion planning. 4/ "Theory of Mind" and interaction. 5/ Consciousness and computation. Practice classes focused on TOPIC 4
Assessment: • The COGAR final mark is based on assignments. Assignments work as follows: • assignments are foreseen to evaluate in itinere how students, individually, understood the concepts and the methodologies after TOPIC 2, 3, and 4;

- for TOPIC 2, the assignment consists of a multiple-choice exam on the matters discussed during classes;
- for TOPIC 3, it consists of a programming-related assignment, in which students will have to design and develop a specific part of a robot architecture;
- for TOPIC 4, it consists of a programming-related assignment, in which students will have to implement relevant traits of a cognitive architecture.

Please note that:

- EMARO-wannabe and JEMARO students have a strict deadline to complete their assignment;
- Ph.D. students attending the course can propose a topic on their own, agreed with us, as an assignment, and do not have any specific deadline;
- the final grade will be a weighted mean of the grades of single assignments.

Recommended texts and further readings: Relevant material will be given by the teacher and the instructors during the lectures

Embedded Systems			
Credits: 5	**Spring Semester**	**Compulsory: No**	
Format	Lectures: 40h	Lab: -	
Lecturer: Enrico SIMETTI			

Objectives:
The active participation to the course lessons (theoretical lessons and lab activities) will allow the student to gain the following skills (for the 4 CFU course version):

- To know what are embedded systems, which are their main architectures, and their main applications
- To know how to program an embedded system based on a microcontroller
- To know how to use the developer tools to compile and download the code
- To know how to configure and program the main peripherals (digital I/O, timers, ADC, PWM, SPI, UART)
- To have basic knowledge on how to design an embedded system
- To be able to identify the main requisites in terms of resources (memory, I/O, communication bandwidth, computational power)
- To be able to identify the peripherals needed for the specific application

At the end of the 6 CFU course version, the student will gain the following additional skills:

- To implement a binary or ascii serial protocol, allowing the microcontroller to interface with a PC
- To use a scheduling mechanism within the firmware, allowing for a better software implementation

Contents:

- What is an embedded system and what are its main characteristics

- Introduction to the basic hardware needed for the realization of an embedded system
  - What is a PCB and what is an integrated circuit
  - Logic gates and combinatorial circuits
  - Latches, Flip flops and sequential circuits
- Architectures of processing systems
  - Basic architecture of a PC
    - ✓ What is a communication BUS, the memory, the CPU and the control unit, what is a register and what is an ALU
  - Specific architectures for embedded systems
    - ✓ ASIC and ASSP
    - ✓ PLD, CPLD and FPGA
    - ✓ Microcontrollers and DSP
    - ✓ Differences between PC and embedded system architectures
- Specific tools for developing code for embedded systems
- Programming embedded systems
  - Peripherals programming
    - ✓ Digital I/O
    - ✓ Oscillator configuration and timers usage
    - ✓ Sensor acquisition through analog-digital conversion (ADC)
    - ✓ Motor control through PWM signal generation
  - Communication with other devices
    - ✓ SPI bus to communicate with another microcontroller
    - ✓ UART communication with a PC
  - Interrupt and event-based programming

- Scheduling
  - Development of a simple function scheduling mechanism within the main program
  - Use of scheduling to simplify the project design

Assessment: Development of a project assigned at the end of the course. Discussion of the project and of the content covered during the lessons.

Recommended texts and further readings:
Slides will be available through aulaweb. In general, notes taken during the module and the slides available on aulaweb will be sufficient to prepare the exam.

The following books can be used for further reading on embedded systems:

- Q. Li, C. Yao, Real-Time Concepts for Embedded Systems, CMP Books, 2003. (ISBN:1578201241).
- D. E. Simon, An Embedded Software Primer, Addison-Wesley Professional, 1999. (ISBN: 020161569X).
- T Noergaard. 2013. A Comprehensive Guide for Engineers and Programmers, Embedded Systems Architecture (2 ed.). Newnes, Newton, MA, USA.
- Peter Hintenaus. 2014. Engineering Embedded Systems: Physics, Programs, Circuits. Springer Publishing Company, Incorporated.

Artificial Intelligence for Robotics II			
Credits: 5 **Spring Semester** **Compulsory: No**			
Format	Lectures: 40h	Lab:	
Lecturer: Fulvio MASTROGIOVANNI			

Objectives:

The main objective of Artificial Intelligence for Robotics II (AI4RO2) is to provide students and scholars with methodological approaches and pragmatic knowledge about how to integrate advanced AI techniques in robot architectures to make them capable of operating in real-world environments in a robust way.

As robots are deployed in scenarios progressively more unstructured, and in conditions whereby their behaviour cannot be easily foreseen in advance, the degree of intelligence they must be provided with becomes of critical importance. Encoding advanced AI algorithms in robots operating in such conditions requires a careful trade-off between their expected capabilities and the associated computational requirements. The problem of defining an AI-based robot architecture requires:

- identifying the proper representation level of sensory information, and its use to guide robot behaviour;
- selecting the most adequate representation approaches to combine sensory information and robot knowledge, which take into account efficiency, computational load, and usability;
- integrating algorithms able to operate on such represented information according to various reasoning approaches, e.g., induction, deduction, abduction;
- connecting the reasoning layer with action-oriented robot motion strategies, which are robust to unforeseen sensory data and events.

AI4RO2 will provide a reasoned treatment of current, state-of-the-art AI-backed perception, cognition, knowledge representation, reasoning, and action approaches, as well as a critical discussion about typical scenarios, use cases, and solutions

Contents:

AI4RO2 is a highly experimental subject. AI4RO2 mixes up theoretical insights about AI techniques with practical knowledge about how to make them work in robots. AI4RO2 is organised around the following topics:

TOPIC 1: Introduction and motivations:

- Introduction to the course
- Differences and extensions with respect to AI4Ro1

TOPIC 2: Knowledge representation and reasoning:

- Knowledge bases and ontologies, the Ontology Web Language (OWL)
- Description Logic and its extensions
- Reasoning in ontologies: subsumption, instance checking, rules.

Practice classes focused on TOPIC 2.

TOPIC 3: Planning in discrete/continuous domains:

- Recap on STRIPS-based planning
- Using classical planners for tasks with continuous operators in robot tasks
- Introduction to PDDL+: syntax and semantics
- Semantic attachments
- Combined task and motion planning

Practice classes focused on TOPIC 3.

TOPIC 4: AI-based robot perception and motion algorithms:

- Probabilistic and quantum-like robot perception models
- Probabilistic motion models
- Belief-space planning

Practice classes focused on TOPIC 4

Assessment:
The AI4RO2 final mark is based on assignments. Assignments work as follows:

- at the beginning of the semester, a number of assignments are proposed;
- students, self-organized in groups of up to 5 people, bid on assignments; each group is required to express 3 ordered preferences;
- we'll try to satisfy the preferences at best and allocate assignments to groups accordingly;
- at that point, work on assignments can start.

Please note that:

- EMARO-wannabe and JEMARO students have a strict deadline to complete their assignment;
- Ph.D. students attending the course can propose a topic on their own, agreed with us, as an assignment, and do not have any specific deadline.

Properly carrying out an assignment means providing:
1/ an appropriate sketch of the solution the group will aim at designing and developing;
2/ a (possibly working, maybe with limitations) solution to the given problem;
3/ properly commented code (in a specific format) and, where appropriate, a tutorial;
4/ a video showing how the developed solution works

Recommended texts and further readings: Relevant material will be given by the teachers and the instructors during the lectures.

Mechanical Design methods in Robotics		
Credits: 5	**Spring Semester**	**Compulsory: No**
Format	Lectures: 14h	Lab: 18h
Lecturers: Matteo ZOPPI and Perla MAIOLINO		

Objectives:

Understanding the relation between use, function and design, starting from simple items and scaling up to robotic systems. Understanding the steps in engineering design of mechanical and mechatronic devices: components and systems; the scope for the student is to become able to manage a design process and to be part of the staff involved: not to be become a designer themselves but to collaborate with designers. Get skills in geometric modelling, adding of functional information, run of structural and multibody simulations using SW for computer aided engineering (CREO of PTC is currently adopted). Develop a design case through the course up to 3D printing and presentation and communication of the process and results.

Contents:

- Mechanical and mechatronic engineering design
- Steps of a design process
- Definition of the architecture and analysis wrt task and function
- Conceptualization and embodiment
- 3D geometric modelling
- Functionalization of the model: dynamic and structural information
- Run of simulations: method and practice
- 3D printing: preparation of models and print; adjustment for assembly

Assessment: Continuous assessment during the semester: 30%. Assessment of performance at the interview: 70%

Recommended texts and further readings: Relevant material will be given by the teacher during lectures.

Signal Processing in Robotics		
Credits: 5	**Spring Semester**	**Compulsory: No**
Format	Lectures: 40h	Lab: TBD
Lecturer: Matteo LODI		

Objectives:

It is expected that at the end of this subject the student will be able to design analog and digital filters, starting from assigned technical specifications, and to simulate them. Moreover, he/she should be able to implement and test the kinds of filters physically realized and tested during the lectures. To this end, he/she has to learn the main peculiar features of each class of filters and the corresponding design techniques described during the classroom lectures. Given a specific filter design problem, the student has firstly to decide what class of filters can be (or has to be) used to solve it. Then he/she can start designing the filter, by using not only the techniques specific for filters, but also general concepts coming from other areas, such as signal processing and automatic controls, as illustrated during the lectures. This capacity of solving non-trivial problems is one of the main elements of the scientific cultural baggage of an engineer.

Contents:

- Introduction to the course.
- Signal-processing chain in robotics applications.
  - The boundary between analog and digital blocks: The Nyquist–Shannon sampling theorem.
  - Anti aliasing filters.
- General concepts about filter synthesis (frequency transforms, ideal and physical filters, adaptation)
- Design of analog filters:
  - Design of doubly-terminated passive filters: Butterworth, Chebyschev, Elliptic and Bessel filters (design techniques, HW lab activity).
  - Design of RC active filters (design techniques, HW lab activity)
- Design of Digital filters:
  - FIR filters (design techniques, Matlab activity
  - IIR filters (design techniques, Matlab activity
  - Adaptive filters (design techniques, Matlab activity)
- Design of integrated filters: Switched-capacitor filters (principles, HW lab activity)

Assessment: Oral: two discussions starting from two questions (one chosen by the student and one asked by the examiner) concerned with the topics treated during the lessons and to the design techniques applied during lab activities. The learning results are assessed through the lab activities and the oral exam.

Recommended texts and further readings:

- Notes provided by the lecturer (main reference)
- C. Bowik, "RF circuits design," Newnes, 1997.
- J.G. Proakis, D.G. Manolakis, "Digital signal processing: principles, algorithms, and applications," Prentice Hall, 1996.
- M.E. Van Valkenburg, "Analog Filter Design," Oxford University Press, 1995.
- A. Liberatore, S. Manetti, "La progettazione dei filtri elettronici," Edizione Medicea, 1985.
- - L.B. Jackson, "Digital filters and signal processing," Kluwer Academic Publishers, 1996.

5.3. Syllabus of the courses offered at Warsaw University of Technology

Signal Processing			
Credits: 5	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Tutorials: 15h	
Lecturer: Włodzimierz KASPRZAK			

Objectives:

To present the methods of description, decomposition and transformation of deterministic signals for both continuous and discrete time cases. To present linear time-invariant systems, Fourier analysis, FIR and IIR filters, the Laplace- and Z transform. To introduce basic knowledge about audio and speech signal processing.

Contents:

- Analog and digital signal conversion. Continuous and discrete signal processing.
- Linear time-invariant 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. Deconvolution and optimal filters.
- Recursive filters. The Laplace- and z-transform. Chebyshev filters.
- Audio and speech signal processing. Methods of time-, frequency- and cepstral-domain processing.

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- 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.
- Lawrence R. Rabiner, Ronald W. Schafer. Theory and Applications of Digital Speech Processing. Pearson, 2011 (chapters 6-9)
- Further readings will be provided by lecturer.

Real-time Systems			
Credits: 5	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Lab: 30h	Guided project: 15h
Lecturer: Tomasz KRUK			

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;
- Processes and threads
- Scheduling in operating systems, real-time scheduling algorithms for periodic tasks
- Synchronization and communication
- Input/output systems
- Protocols for accessing shared resources

Soft real-time systems

- Real-time programming in POSIX
- Thread, mutex and conditional variables
- Interprocess communication for real-time systems

Hard real-time systems

- QnX, VxWorks, Windows CE;

Fundamentals of real-time programming for embedded systems

- Shell programming
- 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.

Assessment: 50% continuous assessment, 50% final exam

Recommended texts and further readings:

- 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.

Modelling and Control of Manipulators			
Credits: 6	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 30 h	Tutorials: 30 h	
Lecturer: Cezary ZIELINSKI and Piotr TATJEWSKI			

Objectives:

This course presents the fundamentals of the modelling and control techniques of serial manipulators. Topics include robot architectures, geometric modelling, kinematic models, dynamic modelling and its applications, as well as the classical decentralized PID control, computed torque control and model predictive control.

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 the Lagrange formalism,
- Dynamic modelling using recursive Newton-Euler method,
- Trajectory generation between two points in the joint space and in the operational space,
- Classical PID control,
- Computed torque control,
- Model predictive control.

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

ecommended texts and further readings:

- Wissama Khalil, and E. Dombre, Modelling, identification and control of robots, Hermes Penton, London, 2002.
- John .J. Craig, Introduction to Robotics: Mechanics and Control, Addison-Wesley/ Pearson/Prentice-Hall, 1986-2009
- Mark W. Spong, Seth Hutchinson, M. Vidyasagar, Robot Modeling and Control, Wiley, 2005

Computer Vision			
Credits: 5	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Tutorials/examples: 15h	

Lecturer: Włodzimierz KASPRZAK / Artur WILKOWSKI

Objectives:

This course presents the fundamentals in computer vision. Topics include image formation, camera calibration, image processing, image segmentation and features, stereo-vision and multi view geometry, RGB-D registration, 3D point clouds, machine learning, deep neural networks in image analysis

Contents:

- Projective geometry and camera calibration
- Image processing
- Stereovision
- Image features
- RGB-D cameras
- Depth map and point cloud - processing
- 3D reconstruction, structure from motion
- Machine learning – regression and classification
- Neural networks and deep learning

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- R. C. Gonzales, R. E. Woods: Digital Image Processing, 4th Edition, Pearson/Prentice Hall, 2018
- 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 • R. Szeliski, Computer Vision: Algorithms and Applications, Springer, 2011 • OpenCV: OpenCV-Python tutorials, https://docs.opencv.org/ • T. Amaratunga, Deep Learning on Windows. Building Deep Learning Computer Vision Systems on Microsoft Windows. Springer, 2021

Neural Networks			
Credits: 5	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Tutorials: 15h	
Lecturer: Andrzej KORDECKI			

Objectives:

The goal of the class is to present neural networks as tools for pattern classification, function approximation and system modelling. 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, system modelling, and other applications.

Contents:

- Introduction: basic ideas, history, applications. Description of the neuron, activation functions, basic characteristics of neural networks. Neural network structures: feedforward and recurrent.
- Machine learning types: supervised, unsupervised and reinforced. Characteristics of input data and data augmentation in neural network learning. Application of neural networks in static and dynamic modeling.
- Loss function and evaluation measures of network results used in regression and classification. Perceptron learning rule. On-line and off-line training. Gradient optimization methods in neural network learning. Back propagation algorithm and its characteristics. Learning Optimizers: SGD, Adagrad, Adadelta, and Adam.
- Characteristics of overfitting and underfitting in neural networks training. Validation methods. Generalization methods of neon networks: regularization, dropout, and batch normalization.
- Neural networks with radial base functions. Support vector machine. Self-organizing maps, Kohonen networks. LSTM recurrent network.
- Convolutional neural networks: description of ideas, structures, learning and their characteristics. Description of basic structures of neural networks in applications of computer vision.
- Basics of Python programming. Neural networks Python libraries in problem formulation. Practical applications of neural networks.

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- S. Haykin, Neural Networks and Learning Machines, Third Edition, Prentice Hall 2009,
- I. Goodfellow, Y. Bengio, A. Courville, Deep Learning, MIT Press 2016,
- G. Dreyfus, Neural Networks: Methodology and Applications, Springer, New York 2005.

Mechanical Design Methods in Robotics			
Credits: 5	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Project: 30 h	
Lecturer: Krzysztof MIANOWSKI			

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).

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- 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

Prerequisites: Modeling and control of manipulators

Robot Programming Methods			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Tutorials: 30h	
Lecturer: Cezary ZIELINSKI			

Objectives:

To learn the robot programming methods.

Contents:

The course starts with motivation for studying robot programming methods and introduces the fundamental concepts. The following are presented: : industrial programming methods, industrial programming languages, robot programming libraries, robot programming frameworks, domain specific languages, toolchains. Then the lecture concentrates on specification of multi-agent robotic systems.

The concept of an agent is presented from different perspectives, leading to the introduction of an embodied agent. Embodied agent’s structure is presented. Transition functions, terminal, error and initial conditions are introduced. This leads to the concept of behaviour and finite state machines switching them.

The general methodology of specification of robotic systems is presented. Subsequently this methodology is presented on three examples: robot group box pushing, robot endowed with visual perception based on a standalone camera and an eye-in-hand setup, robot picking randomly located objects using position-force sensing and vision. Later classification of robotic systems and agents based on diverse criteria is shown. This is followed by historical evolution of robot system architectures. The last lectures are devoted to implementation of robotic systems based on Robot Operating System (ROS).

Assessment: 50% continuous assessment, 50% final exam

Recommended texts and further readings:

- Zieliński C.: Robotic System Design Methodology Utilising Embodied Agents. In: Automatic Control, Robotics and Information Processing, Eds.: P. Kulczycki, J. Korbicz, J. Kacprzyk. Series: Advances in Intelligent Systems and Computing, Vol. 296. Springer 2021. pg. 523–561. DOI: 10.1007/978-3-030-48587-0_17
- Zieliński C.: Specification of Agent Based Robotic Systems Using Hierarchical Finite State Automatons. In: Advanced, Contemporary Control, Proceedings of the 20th Polish Control Conference, Łódź, Poland, 2020, Eds.: A. Bartoszewicz. Series: Advances in Intelligent Systems and Computing, Vol. 1196. Springer 2020. pg. 465–476. DOI: 10.1007/978-3-030-50936-1_39
- Kornuta T., Zieliński C., Winiarski T.: A universal architectural pattern and specification method for robot control system design. Bulletin of the Polish Academy of Sciences–Technical Sciences, Vol. 68, no. 1, 2020. pg. 3–29. DOI: 10.24425/bpasts.2020.131827
- Zieliński C., Winiarski T.: Motion Generation in the MRROC++ robot programming framework. International Journal of Robotics Research. vol. 29, no. 4, April 2010. pg. 386–413. (OnlineFirst, published on September 28, 2009 as doi:10.1177/0278364909348761)
- Lecture notes

Mobile Robots			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Tutorials: 30h	
Lecturer: Wojciech SZYNKIEWICZ			

Objectives:

This course provides an introduction to mobile robots and covers basics required for autonomous mobile robotics. Core course topics include the mobile robot locomotion, legged robots, classification of wheeled robot structures, kinematic models of mobile robots, motion control, sensors for mobile robots, simultaneous localization and mapping, path planning and obstacle avoidance.

Contents:

The following subjects will be addressed:

- Wheeled mobile robots (WMRs), types of wheels, typical mobile robot bases,
- Legged robots
- Holonomic and non-holonomic constraint equations,
- Classification of robots, using the degrees of mobility and steerability, and maneuverability,
- WMRs posture kinematic model,
- WMRs configuration kinematic model,
- Trajectory generation,
- Motion control of WMRsRelative localisation: odometry, inertial systems.
- Absolute localization: GPS, sensor fusion,
- Simulataneous Localization And Mapping (SLAM) Collision avoidance.Path planning.

Assessment: 60% continuous assessment, 40% final exam
Recommended texts and further readings: • C.Canudas, B. Siciliano, G.Bastin (editors), Theory of Robot Control, Springer-Verlag, 1996. (chapters 7,8, and 9). • P. Corke: Robotics, Vision & Control. Fundamental Algorithms in MATLAB. Springer 2017. • H. Choset et al.: Principle of Robot Motion. Theory, Algorithms and Implementation. The MIT Press, 2005. • R.Siegwart et al, Introduction to Autonomous Mobile Robots, The MIT Press second edition 2011. B.Siciliano, O.Khatib,eds Robots Handbook, second edition, Springer-Verlag 2016, Chapters24, 29, 46-49. .

Artificial Intelligence			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Tutorials: 15h	
Lecturer: Włodzimierz KASPRZAK			
Objectives: The goal of the course is to present computational techniques of artificial intelligence as applied for computerized autonomous agents. The first part covers methods of knowledge representation and deductive inference – first-order (predicate) logic, fuzzy logic and Bayesian models. The second part deals with deterministic and probabilistic state-space search and planning algorithms. The third part is devoted to machine learning by observation (inductive inference) – clustering, classification and approximation (regression) techniques. **Contents:** • Computational agents in first-order (predicate) logic – representation and inference • Path search in state space • Solution search • Action planning – plan search • Fuzzy logic • Bayesian nets – representation and inference • Dynamic Bayesian nets • Decision nets, MDPs and reinforcement learning • Machine learning - estimation and regression techniques • Learning by observation – clustering, classification and function approximation			
Assessment: 30% continuous assessment, 70% final exam			
Recommended texts and further readings: • S. Russell, P. Norvig, Artificial Intelligence: A Modern Approach. Prentice Hall, Upper Saddle River, N.J., 3d ed. 2011, 4th ed. 2020. http://aima.cs.berkeley.edu/ • D. Barber, Bayesian Reasoning and Machine Learning, Cambridge University Press, 2012. http://www.cs.ucl.ac.uk/staff/d.barber/brml/ • Charu C. Aggarwal, Neural Networks and Deep Learning. A Textbook. Springer, 2018. • M. Flasiński, Introduction to Artificial Intelligence, e-book: Springer, 2016, https://www.springer.com/us/book/9783319400204			

Embedded Systems			
Credits: 4 **Spring Semester** **Compulsory: Yes**			
Format	Lectures: 30h	Tutorials: 15h	
Lecturer: Visiting Professor			
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:** The following topics are treated: • General overview of existing families of micro-controllers, • 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 programming for embedded systems. • Exercises using equipment – programing and executing the real-time tasks			
Assessment: 30% continuous assessment, 70% final exam			
Recommended texts and further readings: • Q. Li, C. Yao, Real-Time Concepts for Embedded Systems, CMP Books, 2003. (ISBN:1578201241). • D. E. Simon, An Embedded Software Primer, Addison-Wesley Professional, 1999. (ISBN: 020161569X) • A. S. Berger, Embedded Systems Design: An Introduction to Processes, Tools and Techniques, CMP Books, 2001. (ISBN: 1578200733).			

Optimization Techniques			
Credits: 4 **Spring Semester** **Compulsory: Yes**			
Format	Lectures 15 h	Tutorials 15 h	
Lecturer: Janusz GRANAT			
Objectives: The main objective of the course is to introduce its participants to the theory and solution methods for optimization problems in science and technology. The students will be able to: understand various theoretical and computational aspects of a wide range of optimization methods, realize the capabilities offered by various optimization methods, use of optimization toolboxes. **Contents:** • Concepts and models of mathematical programming • Linear programming • Basic concepts and theory of unconstrained optimization			

- Algorithms for nonlinear unconstrained optimization
- Theory of constrained optimization
- Algorithms for nonlinear constrained optimization
- Duality in optimization

Assessment: 40% continuous assessment, 60% final exam (2h)

Recommended texts and further readings:

- H.P. Williams, Model Building in Mathematical Programming, 5th Ed, Wiley 2013.
- M.S. Bazaraa, J.J. Jarvis, H.D. Sherali, Linear Programming and Network Flows, 4th Ed, Wiley, 2010.
- M.S. Bazaraa, H.D. Sherali, C.M. Shetty, Nonlinear Programming, Wiley, 2006.
- A.P. Ruszczyński, Nonlinear Optimization, Princeton Univ. Press, 2006.
- I.Maros, Computational Techniques of the Simplex Method, Kluwer, 2003.
- M.Ehrgott, Multicriteria Optimization, Springer, Berlin 2005.

Group Project			
Credits: 5 Spring Semester Compulsory: Yes			
Format	Project: 75h		
Lecturer: Teresa ZIELINSKA and professors at WUT			

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.

Contents:

The course is divided into two parts:

- Introduction to project (organization, process, …)
- Initiating, planning, executing, controlling and closing a project,
- responsibility

- Solution of robotic problem with innovative function or structure. The problem solution should be defined by the group and must make use of sensors and control algorithms.

Assessment: 100% Course Work, based on the documentation produced at each stage of the process, a presentation and demonstration of the final product, the effectiveness of the team's management of the project, and the understanding and contribution of each individual.

Recommended texts and further readings:

- Recommended texts will be given by the lecturers.

Prerequisites: All compulsory modules from first semester

6. ANNEX 2: LIST OF THE SECOND YEAR MODULES IN JAPAN

2023 Course List for International Graduate Programs (April 2023 - March 2024)

Program	Code	Subject	Sem.	Cr.	Time	Room	Lecture Type	Professor
General Courses	09764	SCIENCE,TECHNOLOGY AND CULTURE	Fall	2	Wed.2	12-105	①	MIKAMI KOICHI
	09798	ADVANCED COURSE OF MOLECULAR DYNAMICS	Fall	2	Mon.5	-	②	YASUOKA KENJI
	00183	MATHEMATICAL ENGINEERING FOR QUANTUM MECHANICS	Fall	2	Thu.4	14-202	①	YAMAMOTO NAOKI
	12456	ADVANCED COURSE ON SPIN AND NANO-SCALED SOLID STATE PHYSICS	Spring Q2*1	2	Mon.5/Thu.2	12-102	①	KAIJU HIDEO and the others
	02133	INTELLIGENT MACHINE SYSTEM	Fall Q3*1	2	Mon.1/Mon.2	12-208	③	MURAKAMI TOSHIYUKI
	00255	NON-LINEAR DYNAMICS IN CHEMICAL SYSTEM	Spring	2	Tue.1	12-206	③	ASAKURA KOICHI
		TOPICS IN APPLIED PHYSICS A						Not offered in 2023
		QUANTUM ELECTRONICS						Not offered in 2023
		SUPERCONDUCTIVITY AND SOLID STATE ENGINEERING						Not offered in 2023
	11411	SPECIAL TOPICS ON ENGINEERING FOR SYNTHESIS AND DESIGN A	Fall (Intensive)	2	*3	-	①	ISSAKOV VADIM
	02387	ULTRAPRECISION MACHINING AND METROLOGY	Fall	2	Mon.2	12-103	①	YAN JIWANG
	02391	MEMS: DESIGN AND FABRICATION	Spring	2	Thu.2	12-105	③	MIKI NORIHISA and the others
	01950	MECHANICAL INTERFACE DESIGN	Fall	2	Thu.3	12-105	③	MORITA TOSHIO
	00217	SPACE EXPLORATION ENGINEERING	Fall	2	Fri.2	14-201	①	ISHIGAMI GENYA
	01304	BIOMIMETIC MICRO/NANO ENGINEERING	Spring	2	Mon.3	12-109	③	ONOE, HIROAKI and the others
	13400	MECHANICS OF FLEXIBLE MATERIALS AND STRUCTURAL DESIGN	Spring	2	Mon.5	12-108	①	SANO TOMOHIKO
	11699	ADVANCED CONTROL SYSTEMS DESIGN	Spring	2	Mon.2	12-105	①	OHMORI HIROMITSU and the others
	07981	APPLIED SYSTEM DESIGN ENGINEERING	Fall	2	Thu.3	14-204	①	BEAUCAMP ANTHONY
	02258	DIGITAL SYNTHESIS OF FORMING PROCESSES	Spring	2	Mon.5	12-105	①	OYA TETSUO
	06913	DIGITAL WIRELESS COMMUNICATIONS	Spring	2	Mon.2	14-211	①	SANADA YUKITOSHI
	09946	OPTICAL CONTROL OF QUANTUM SYSTEMS	Spring	2	Wed.2	14-204	①	SAIKI TOSHIHARU and the others
	07829	OPTO-ELECTRONICS	Spring	2	Thu.1	12-208	①	KANNARI FUMIHIKO
	07795	PHOTONIC NANOSTRUCTURE	Fall	2	Thu.3	12-202A	①	TANABE TAKASUMI
	00221	ADVANCED SIGNAL PROCESSING	Spring	2	Wed.1	12-106	③	YUKAWA MASAHIRO
	00236	ADVANCED SYSTEM ELECTRONICS	Fall	2	Tue.2	-	④	KUBO RYOGO
	11722	LASER PROCESSING	Fall	2	Mon.3	12-101	①	TERAKAWA MITSUHIRO
	11737	ORGANIC ELECTRONIC MATERIALS AND DEVICES	Spring	2	Fri.1	12-211	①	NODA KEI
	13099	COGNITIVE ROBOTICS	Spring	2	Fri.5	12-102	②	MURATA SHINGO
	11426	CHEMICAL SENSORS / BIOSENSORS AND SENSING MATERIALS	Spring	2	Tue.2	12-206	①	CITTERIO DANIEL
	12456	ADVANCED COURSE ON SPIN AND NANO-SCALED SOLID STATE PHYSICS	Spring Q2*1	2	Mon.5/Thu.2	12-102	①	KAIJU HIDEO and the others
	08677	INTRODUCTION TO COMPUTATIONAL SOLID MECHANICS	Spring	2	Tue.2	12-103	①	ISAKARI HIROSHI
	00255	NON-LINEAR DYNAMICS IN CHEMICAL SYSTEM	Spring	2	Tue.1	12-206	③	ASAKURA KOICHI
	07044	COMPUTER VISION	Spring	2	Mon.5	14-202	①	SAITO HIDEO
	08495	COMPUTER ARCHITECTURE	Spring	2	Thu.1	12-203/14-203	①	AMANO HIDEHARU and the others
		SPECIAL TOPICS ON ENGINEERING FOR SYNTHESIS AND DESIGN B						Not offered in 2023
		MATHEMATICAL AND PHYSICAL METHODS IN FLUID DYNAMICS						Not offered in 2023
		NANO-ELECTRONICS						Not offered in 2023
		OPTICAL NETWORK SYSTEM						Not offered in 2023
	00733	ENVIRONMENTAL INFORMATION SYSTEM ARCHITECTURE	Spring	2	Wed.6	-	②	YASUOKA, KENJI and the others
	01065	ENVIRONMENTAL TECHNOSCIENCE AND POLICY	Spring	2	Mon.4	-	②	YASUOKA, KENJI and the others
	08677	INTRODUCTION TO COMPUTATIONAL SOLID MECHANICS	Spring	2	Tue.2	12-103	①	ISAKARI HIROSHI
	00346	ANALYSIS OF ARCHITECTURAL FORM	Fall	2	Fri.5	34-321	①	ALMAZAN CABALLERO JORGE
	00255	NON-LINEAR DYNAMICS IN CHEMICAL SYSTEM	Spring	2	Tue.1	12-206	③	ASAKURA KOICHI
	09544	COMPRESSIBLE FLUID DYNAMICS	Spring Q1*1 (Every other week)	2	Mon.2/Wed.1	12-102	②	MATSUO AKIKO
	00767	ADVANCED COURSE IN APPLIED AND COMPUTATIONAL MECHANICS 2	Fall	2	Mon.1	14-204	②	ANDO KEITA and the others
	01983	ADVANCED ACTUATOR ENGINEERING	Fall	2	Tue.2	12-202A	③	TAKEMURA KENJIRO
	09798	ADVANCED COURSE OF MOLECULAR DYNAMICS	Fall	2	Mon.5	-	②	YASUOKA KENJI
	02430	FUNDAMENTALS OF TURBULENCE AND ITS THEORY	Spring	2	Fri.2	12-206	③	FUKAGATA KOJI
	02224	INTRODUCTION TO TURBULENCE MODEL AND ITS APPLICATION	Fall	2	Tue.5	12-209	②	OBI SHINNOSUKE
	00475	FUNDAMENTALS OF MULTIPHASE FLOW	Spring	2	Tue.3	11-21	②	ANDO KEITA
	09248	FINITE ELEMENT MODELING AND SIMULATION	Fall	2	Tue.1	12-206	②	MURAMATSU MAYU
	12289	MECHANICS AND NUMERICAL SIMULATION OF ADVANCED MATERIALS	Spring	2	Tue.2	11-21	②	TAKANO NAOKI
	12786	NONLINEAR DYNAMICS	Fall	2	Thu.5	12-206	②	PENG LINYU
	08772	TOPICS IN COMPUTER OPERATING SYSTEMS	Spring	2	Tue.3	12-108	①	KONO KENJI
	08017	ADVANCED COURSE IN DATABASE SYSTEMS	Spring	2	Thu.5	12-109	①	TOYAMA MOTOMICHI and the others
	02535	MICROPROCESSOR ARCHITECTURE	Fall	2	Thu.3	12-103	①	YAMASAKI NOBUYUKI
	08419	FORMAL PROGRAMMING LANGUAGE THEORY	Fall	2	Thu.4	12-202A	①	TAKIMOTO MUNEHIRO
	00480	COMPUTER SCIENCE: EXERCISES	Fall	2	-	*4	①	TAKADA SHINGO and the others
	08442	ADVANCED COURSE ON NATURAL LANGUAGE PROCESSING	Fall	2	Wed.2	12-108	①	OHARA KYOKO and the others
	03637	DESIGN OF PHYSICALLY GROUNDED COMMUNICATION SYSTEM	Spring	2	Fri.2	12-101	①	IMAI MICHITA
	03292	ADVANCED COURSE ON NETWORK ENGINEERING	Fall	2	Mon.4	12-106/14-B101	①	TERAOKA FUMIO
	11536	SOFTWARE ENGINEERING: DEVELOPMENT AND TESTING	Spring	2	Tue.5	12-101/12-102	①	TAKADA SHINGO
	02057	ADVANCED COURSE ON COMPUTER VISUALIZATION	Spring	2	Thu.4	14-201	①	FUJISHIRO ISSEI

Program	Code	Subject	Sem.	Cr.	Time	Room	Lecture Type	Professor
Science for Open and Environmental Systems	00494	ADVANCED COURSE ON NETWORK SERVICES	Fall	2	Fri.2	12-105	①	KANEKO KUNITAKE
	08476	REAL WORLD INTERACTIVE SYSTEM	Fall	2	Tue.2	14-204	①	SUGIURA YUTA
	07044	COMPUTER VISION	Spring	2	Mon.5	14-202	①	SAITO HIDEO
	08089	ADVANCED COURSE ON DIGITAL COMMUNICATION THEORY	Spring	2	Tue.2	14-204	①	SASASE IWAO
	03288	ADVANCED COURSE OF INTERNET BACKBONE ARCHITECTURE	Spring	2	Mon.2	14-204	①	YAMANAKA NAOAKI
	02903	AD HOC AND SENSOR NETWORK	Fall	2	Mon.3	14-201	①	OTSUKI TOMOAKI
	08495	COMPUTER ARCHITECTURE	Spring	2	Thu.1	12-203/14-203	①	AMANO HIDEHARU and the others
	00805	MIXED REALITY	Spring	2	Mon.3	12-211	①	SUGIMOTO MAKI
	11134	MODELS FOR CONCURRENCY	Spring(Intensive)	2	*5	-	①	YOSHIDA NOBUKO
	13118	MACHINE INTELLIGENCE	Spring	2	Fri.4	12-108	①	SUGIURA KOMEI
	08165	HUMAN-AGENT INTERACTION	Spring	2	Tue.4	12-108	①	OSAWA HIROTAKA
	01816	ADVANCED FINANCIAL ENGINEERING 1	Spring	2	Tue.3	12-202B	①	IMAI JUNICHI
	08112	APPLIED STATISTICAL ANALYSIS	Fall	2	Mon.2	12-209	①	SUZUKI HIDEO
	02061	OPERATIONS MANAGEMENT	Fall	2	Mon.2	14-203	③	MATSUKAWA HIROAKI
	02076	OPEN SYSTEMS MANAGEMENT: LECTURE AND LABORATORIES	Fall (Every other week*7)	2	Thu.4/Thu.5	14-211	①	YAMADA SHU and the others
	08696	ADVANCED TOPICS IN BUSINESS ECONOMICS 2	Fall	2	Fri.4	12-104	①	BANDO KEISUKE
	11149	ADVANCED COURSE ON APPLICATION OF EXPERIMENTAL DESIGN	Fall	2	Fri.5	12-207	①	YAMADA SHU
		DISTRIBUTED SYSTEMS						Not offered in 2023
		DYNAMICS IN ARCHITECTURAL ENGINEERING						Not offered in 2023
		PUBLIC SPACE AND COMMUNICATION						Not offered in 2023
		ADVANCED THEORY OF CONTEMPORARY ARCHITECTURAL DESIGN						Not offered in 2023
		THERMAL AND REACTIVE FLUID DYNAMICS						Not offered in 2023
		SYSTEMS PERFORMANCE EVALUATION						Not offered in 2023
		ADVANCED COURSE ON TOTAL QUALITY MANAGEMENT						Not offered in 2023
Faculty of Science and Technology	06545	STABILITY THEORY IN DYNAMICS SYSTEMS／SPECIAL LECTURE IN MATHEMATICAL SCIENCE 1	Fall Q4*1	2	Mon.2	12-101	①	PENG LINYU
	11961	SPECIAL LECTURE IN MECHANICAL ENGINEERING	Spring Q1*1	2	Mon.5	12-104	①	PENG LINYU
	42762	INTRODUCTION TO FLUID MECHANICS	Fall Q4*1	2	Tue.2	D204 *6	①	ANDO KEITA
Japanese	01027	JAPANESE ELEMENTARY CONVERSATION	Fall	1	Wed.3	12-208	①	TAKEMURA
	13266	JAPANESE 1 (E)	Fall	1	Wed.3	12-102	①	ITO
	13285	JAPANESE 1 (F)	Fall	1	Wed.4	12-102	①	ITO
	03182	JAPANESE 2 (A)	Fall	1	Wed.3	12-202C	①	SANAI KAORU
	05515	JAPANESE 3 (A)	Fall	1	Wed.4	14-204	①	SANAI KAORU
	03311	JAPANESE 3 (B)	Spring	1	Wed.4	12-208	①	SANAI KAORU
	05850	JAPANESE 4 (A)	Fall	1	Wed.5	12-202A	①	YUGE
	03269	JAPANESE 4 (B)	Spring	1	Wed.4	12-202A	①	HAYASHI KAORI
		JAPANESE 5 (A)						Not offered in 2023
		JAPANESE 5 (B)						Not offered in 2023

*1 Most courses are taught on a semester system, but the courses marked "Q1" "Q2" "Q3" or "Q4" are conducted on a quarter system which divides a semester into two halves.
Spring Q1courses: April to May
Spring Q2 courses: End of May to July
Fall Q3 courses: September to mid-November
Fall Q4: Mid-November to January
Please confirm page 8-9 of the "Course Guidebook" for Academic Year class schedule.
*3 "SPECIAL TOPICS ON ENGINEERING FOR SYNTHESIS AND DESIGN A": This is an intensive course. Lecture days have not been decided yet. Please ask the Academic Services in the Office of Stuedent Services.
*4 "COMPUTER SCIENCE: EXERCISES": This course does not have lectures.
*5 "MODELS FOR CONCURRENCY": This is an intensive course. Lecture days are as follows: Aug.3(1-5period), Aug.4(1-5period), Aug.5(1-4period)
*6 This class is held in Hiyoshi Campus.
*7 "OPEN SYSTEMS MANAGEMENT:LECTURE AND EXERCISES" : Lecture days are as follows: Oct.19, Nov.2,16,30, Dec.14, Jan.11

【Type of Classes】
① : Face to Face Classes (conducted mainly in-person)
② : Online Classes (mainly real-time format)
③ : Online Classes (manily on-demand format)
④ : Online Classes (completely on-demand format)
For more information, please attend the first class and check with the instructor.

yellow: mandatory
green: recommendation for Fall Semester