University POLITEHNICA of Bucharest

Faculty of AUTOMATIC CONTROL and COMPUTERS

Master of Science
Robotics and Automation

Course description

C11: Robot Motion Planning and Control

The general objective of the course is to transfer knowledge about the methodology, principles and implementing solutions for robot motion planning, control and tracking, and to apply the acquired knowledge in software programs guiding industrial robots along complex motion trajectories in individual, inter-robot or human-robot collaborative tasks in which they interact with material flow components and the work place environment. The course introduces the main classes of industrial robot arms (Cartesian, revolute and SCARA); students are taught how to create, edit, debug and execute robot programs for free and constrained motion in structured environments with control primitives derived from procedural motion techniques, mathematical constructions and CAD files. Master-slave collaborative robot architectures and fault-tolerant communication protocols are presented. Students are taught how to design, configure, program and deploy customized robot controllers and multi-tasking software systems for particular, non-conventional manipulator structures: multiple-arm robots, robot arms fixed on mobile platforms or redundant, high-dexterity manipulators. The students will work in laboratory activities with real industrial robot systems manufactured by ABB (Sweden) and Adept Technology (USA), and will learn how to configure, install, calibrate, learn, program them in V+ and RAPID languages used currently on large scale in industry. Robot integration in new applications in terms of feasibility of motion trajectories and collision avoidance will be demonstrated using a simulator of virtual robots embedded in a digital work cell.

C12: Guidance Vision in Robotics

The general objective of the course is to present the principles, algorithms of image processing and implementing techniques of 2D and 3D robot-vision vision systems used in manufacturing, logistics and services: 1) visual guidance of robot motions (GVR), vision-based management of material flows in shop floor workplaces, storages and conveyor belts (VMF); 2) automated visual measurement and inspection (AVI) of material flow components and assembly alignments. The course analyses and explains the main functionalities of a robot-vision system: object recognition and locating, creating vision-based robot grasping models and collision-avoidance models, and accurate robot-scene calibration. The most used vision-based robot motion guidance principles are introduced: ‘Look-and-move’ and ‘Visual servoing’ from fixed, down looking and mobile, arm-mounted 2D video cameras and 3D imaging systems, for the interaction with stationary and moving objects. The laboratory activities are done with industrial 2D and 3D vision sensors, cameras, scene lighting and imaging technologies that allow extracting accurate and robust feature data from images of stationary and moving objects. The students will learn to configure and install goal-, environment- and material flow- dependent virtual cameras for setting up of industrial 2D and 3D robot-vision applications: part handling, visually tracking work trajectories, content management of unstructured storages, bin picking, 2D and 3D geometry measurements.

C13: Mechatronics Engineering

The general objective of the course is to present the main manufacturing resources (CNC machines, manipulators, conveyors, part storages and pickers, sensing devices and actuators) and their controllers. The students will learn the functional principles and operating modes of smart sensing and actuating elements used in automation and robotics, the specific data flows and control solutions. There will be presented the main components of robot systems: joints, links, end-effectors, grippers, power supplies, force and displacement sensors, gears, motors and direct drive systems, security and presence detection devices. The students will get familiar and will be able to use methods and algorithms for: efficient control of shop floor devices; obstacle detection and avoidance; part transfer, qualification and handling; automatic diagnosis of controlled resources and product traceability. The students will understand the principles of part processing using material removing techniques with CNC machine tools; they will program in the standard ISO language (G-Code) for $2^{1/2}$ CNC milling machines. The theoretical knowledge acquired in lectures allows them to develop individual applications that will be integrated in team projects.

E11: Embedded Systems for Industrial Control

The course transfers specific knowledge necessary for the design of microcontroller system components and basic software system (operating system, utilities, testing), and the development of applications for the control of industrial processes, robot systems, material flow transport and management of services. In particular, the course will teach microcontroller design requirements, principles and techniques for embedding intelligence in industrial assets (resources, products and orders), and solutions for the interaction of the microcontroller systems with the environment according to the 'edge computing' technology. The practical laboratory activities use integrated microprocessor families which are found on large scale in industrial applications (Intel MCS51, Microchip/Atmel AVR, Microchip PIC, Arduino IDE). The students will learn: hardware design methods, how to configure and select the set of microcontroller elements and the power supply, which are the necessary stages to design, realize and test the PCB support, how to assemble components on mechanical support boards; software design considerations, communication protocols and security; specialized real time operating systems and how to develop, test and debug software control applications for industrial systems.

E12: Machine Learning Methods and Applications

The course transfers knowledge about data processing, machine learning and optimization methods and techniques and their application for data mining in industrial process control and robot applications. The specific teaching objectives are: i) Presentation of the machine learning techniques and functionalities; ii) Formulation of a machine learning problem using Big Data techniques, in terms of: covariance of metrics, merging and aligning information, map-reduce techniques, time series analysis and pattern construction; iii) creating a system able to extract information from data and take optimal decisions; iv) presenting learning methods: supervised / unsupervised learning, reinforcement learning, deep neural networks, statistical learning and related optimization techniques. Applications of the theoretical concepts include: feature classification and clustering, regressions, recurrent neural networks, optimization and control, estimation. similarity matching, data reduction, deviations detecting, co-occurrence grouping and prediction. These concepts and methods are exemplified in industrial applications: optimization of large-scale scheduling problems based on forecasted costs of resource usage, detection state anomalies and predictive resource maintenance.

C21: Mobile Robots and Collective Control

The course is devoted to the study of mobile robots and collective control, covering essential knowledge and algorithms that are required in order to achieve autonomy capabilities of mobile robot systems. The course develops theoretical constructions which are exemplified in case studies, providing thus a broad and solid base of understanding through examples and so making abstract concepts in mobile robotics tangible. The course covers topics from mathematical modelling of motion for wheeled mobile robots, localization and path planning, control algorithms, to the control of multiple-robot systems. Throughout the course, practical, real-life examples are given for all its taught chapters. After finishing this course, the students will have a thorough understanding of how mobile robots work, what are their specific applications and how can they be programmed to achieve certain goals. The computational foundation of this course is MATLAB; dedicated mobile robotics toolboxes (native Matlab toolbox and Peter Corke's open source Mobile Robotics Toolbox) will be used. Additionally, working with proximity and contact sensors, wheel encoders, actuators, and vision sensors is illustrated by using Python and ROS software environments. Selected control algorithms will be implemented in laboratory work on real mobile robots - Khepera, Koala, e-puck, and Kilobot.

C22: Multi-Agent Systems and Programming

The course transfers knowledge about the concepts of autonomous agent and multi-agent system (MAS) and the application of these notions in modelling and control of distributed processes.

The principal frameworks for the development of multi-agent applications: JADE, Erlang, JACK, Netlogo, 3APL are analysed with informational architectures for running industrial applications, as well as methods and techniques for data replication and information redundancy. The course provides knowledge about the basic functionalities of agents and analyses cooperation principles between agents. The students will learn how to develop a multi-agent system and select a platform for developing multi-agent applications; they will acquire knowledge on using multi-agent technologies to solve applications in the field of decentralized control of multi-robot and industrial automation systems. The course exemplifies the principles of distributing intelligence through multi-agent systems in heterarchical and semi-heterarchical manufacturing control topologies. There will be analysed the realization of the physical-informational link between physical production entities (resources, products and production orders) and their information counterparts - multi-agent systems. The objective of the project is to present the work stages for the design of MAS for distributed applications. Students will work out applications of control with distributed intelligence and product-driven automation, using the open source JADE platform integrated with Eclipse.

C23: Smart Robot Learning

The general objective of the course is to present the concepts, theoretical aspects, methods, and techniques used in the field of smart robot learning systems. Knowledge is transferred about practical details of the implementation phase of the analysed methods and techniques. The course provides an overview of the smart robot learning topic, which is then detailed: i) understanding the concept of reinforcement learning, the theory and its implementation aspects; ii) presenting the concept of programming by demonstration, extending this concept for the understanding of knowledge acquisition, movement recognition and movement primitives; iii) analysing the human-robot interaction (learning, coaching) and on-line modifications of robot trajectories; iv) presenting the concept and implementation aspects of kinaesthetic learning; v) analysing collision detection solutions in smart robots learning. Students will be familiar with robot learning from manipulative gestures, gestures analysis and recognition, gesture interpretation. Also, the aspects of deep-learning in robotic manipulation and robotic grasping will be presented to students. The course provides knowledge in the domain of Artificial Intelligence concerning the support and implementing solutions for smart robot learning based on neural networks, fuzzy learning and genetic algorithms exemplified with genetic programming for self-learning robots. The practical laboratory activities use Java and the Integrated Development Environment, and OpenCV for applications of gesture analysis, gesture recognition, and gesture interpretation.

E21: Cloud Manufacturing Models and Services in Robotics

The general objective of the course is to transfer knowledge about the technologies involved in cloud computing and how these technologies can be used in order to develop cloud robotics and cloud manufacturing systems and services. The specific objectives are: presenting the cloud features and facilities and how cloud computing is different from other solutions like grid computing, high performance computing systems, high availability systems or virtualized systems; presenting the three main classes of cloud systems: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) with their functions and advantages; understanding the relationships between cloud components: a) Self Service Interface, b) Service Request Manager, c) Service Automation Engine, d) Provisioning Manager, e) Service Catalogue; familiarizing students with cloud infrastructure design, planning and installation. The course analyses the role of the administration interface to define and manipulate service definition templates and service management plans, and how to use software agents for automatic deployment. The students will understand the standards which build up the foundation of cloud computing and the protocols used to access a cloud system and to manipulate data, with accent on REST and MQTT. They will be also taught how to create and integrate services in cloud to support robotics and manufacturing applications: creating and integrating software services in cloud (for IaaS and SaaS), integrating the services with robot applications or applications running in manufacturing environments. During the laboratory activities there will be presented case studies for workload migration in cloud and different industrial applications which benefit from the capabilities of cloud infrastructures. The students will work with different cloud systems and create applications for them; they will study the CMfg (cloud manufacturing) system security issues and how vulnerabilities can be mitigated.

E22: Intelligent Image Processing

The general objective of this course is to explain the principles, methods and implementing solutions for intelligent image processing with applicability in industry. Presentation of hardware and software solutions for automation in industry, based on computer vision. Specific machine learning methods for the classification, error detection, quality inspection, analysis of situations and action planning that enable automation at industry level are approached. Students will learn medical image processing algorithms and techniques, and computer vision methods for augmented reality in industry (with focus on manufacturing, textile industry, industrial agriculture and healthcare). During laboratory activities, students will become familiar with different types of cameras that are used for image processing in industrial applications (thermal cameras, depth cameras, devices for augmented reality, etc.). Working with single RGB / multispectral / medical images or with videos, acquired during the lab from real cameras or imported from files. Creating computer vision applications in OpenCV/OpenGL and C++: low-level image processing (texture analysis, general segmentation and feature extraction), using neural networks for classification, inspection and error detection (the Tensor Flow library).

C31: Natural Human-Robot Interaction

The course presents specific knowledge necessary for understanding and applying human-robot interaction methods and concepts that can ensure a safe and productive collaboration. The specific objectives are: familiarity with generic robotics concepts such as sensors, effectors and controllers; a theoretical and practical study of obstacle detection and avoidance models; human command detection: gesture detection as a natural human control interface; human-robot interaction concepts, challenges and solutions; human-swarm interaction: benefits and constraints. The laboratory introduces the Robot Operating System (ROS) and the free robot simulator (V-REP for Webots). Practical activities exemplify human-robot interaction methods (command types and complexity, programming by demonstration) and human-swarm interaction with an emphasis on situational awareness with respect to the level of autonomy.

C32: Unmanned Aerial Vehicles

The course presents specific knowledge necessary for understanding and applying motion planning and control methods for unmanned aerial vehicles working into a complex environment (with obstacles, communication restrictions) and within a heterogeneous system (communication with other UAVs and ground-based sensors). The specific objectives are: familiarity with the notions associated to unmanned aerial vehicles (modelling, construction, etc.); understanding motion planning strategies (online versus offline), communication and control limitations; integration into a heterogeneous environment (communication with ground sensors, integration into a WSN – wide sensor network); understanding the role of image analysis (payload stabilization, feature extraction); validation in simulation for real life-inspired applications (from precision agriculture, target surveillance, search and rescue operations, etc.).

C33: Industrial IoT and Big Data Integration

The course presents design methodologies of data processing and communication architectures that are currently used for the convergence between the most recent advances in the information technology domain (IT: IoT, Big Data, Cloud virtualization and web services) and operational control technology (OT: PLC, CNC, industrial robots, SCADA). The specific objectives of the course are: providing context awareness for the parallel evolution of the IT and OT technologies with regards to industrial data access; acknowledging the need for the IT-OT connection and explaining the methods for achieving this linkage; presenting various communication protocols and standards in the Industrial IoT (IIoT) and the directions towards which they are evolving – unification, security and high availability; describing the technical means for the management of large data amounts collected from sensors and the ways in which these big data volumes can be efficiently processed (by specific big data technologies). The course analyses several possibilities of decentralization and distributing data processing towards the peripheral layer of hierarchical control systems (e.g. Cyber-Physical Production Systems), using 'edge computing' technology. The laboratory offers students the possibility to work with physical circuits and platforms:

interfacing Raspberry Pi with sensors and actuators, programming the software interface for integration with the MQTT server, working with the STM P-NUCLEO-WB55 development kit based on ARM Cortex M4F microcontroller architecture, experimenting with 802.15.4 radio standard and the LoRa RFM95W radio module, ‘bridging’ LoRa to Internet – LoraWAN.

E31: Robots in Industrial Applications

The general objective of the course is to transfer knowledge about the integration of industrial robots in already existing industrial structures, in order to add new production capabilities or to enhance the production. The course introduces key performance indicators (KPI) for production lines and the techniques used to improve them, standards about robot-PLC integration, robot installation and safety. The specific objectives are: a) familiarizing students with the standards and procedures for robot installation in a factory work cell, wiring standards for power supply, compressed air, network and digital I/O signal connectivity; b) presenting the requirements and restrictions for developing industrial applications using robots: workspace and safety restrictions, cycle time restrictions and integration standards requirements; c) presenting the methodology for selecting the robot type and controller options for industrial applications depending on the type of the task involved, the payload used in the task, robot speed, communication requirements and complexity of the application; d) understanding: the methodology used in order to develop safe and efficient robot applications and the task optimization process, the implications related with the cycle time and quality of the final product, and the implications regarding the robot life time. The students will be familiar with industrial robot maintenance programs, operations that must be executed, time ranges for maintenance and planning the maintenance windows in a production environment. They will understand the methods used to define and optimize the robot paths to avoid stress in robot joints, rapid direction changes during the motion or sharp accelerations. Students will be taught how to integrate vision systems with industrial robots for visual robot guidance and control, and how to create robust robot applications integrated with safety frameworks (such as PROMIA). The laboratory presents a number of case studies for industrial robot applications and explains the challenges and solutions for particular cases, while working with different industrial robot systems and robot simulators.

E33: Intelligent Manufacturing Systems

The course transfers knowledge about the concept of intelligent manufacturing control of batch production with focus on how hybrid centralized-decentralized control systems are implemented. The following problems of manufacturing control are approached: the functions and organization of Manufacturing Execution Systems (MES); the holonic manufacturing paradigm: holons and holarchies, control models, semi-heterarchical informational topologies, optimization and reality-awareness in Holonic MES (HMES); the System Scheduler and global optimization of batch production; the Cloud Manufacturing (CMfg) model and comparative analysis with Cloud

Computing; Cyber-Physical Production Systems (CPPS): organization, functions, instrumenting, and plug-and-produce principle; using Machine Learning (ML) techniques for predictive order scheduling and resource allocation, and for predictive resource maintenance; the Industry 4.0 concept and implementing framework based on Industrial IoT, edge computing and digital twin technologies. The laboratory offers students the possibility to acquire practical experience by working with a real 6-station Cloud manufacturing platform with multiple robots, CNC machine tools, closed loop shop floor conveyor and processing power embedded on intelligent products during their manufacturing.

Scientific research and practice (sem. I, II, III)

The objectives of the course, replicated on three teaching semesters, consist in training and qualifying master students in research and innovation activities in systems engineering subjects, in granting them support to develop consistent research projects and to disseminate the scientific results obtained. The course presents the principal methodological aspects of scientific research, development and innovation (RDI): introducing the RDI-specific terminology and link between research and industrial activities, describing the RDI system in Romania in the domains of robotics and industrial process automation; selecting the strategies, methods, techniques and tools for the development and implementation of a research project; applying in practice the knowledge, activities and results of the scientific research: types of research activities, documenting and data collecting methods in the scientific research; stages of a scientific research, working plan of a research project.

C41: Artificial Ethics and Legal Issues in Robotics

The general objective of this course is to provide students the necessary elements to understand and address the Ethical, Legal and Societal issues (ELS) in robotics and intelligent systems that are targeting today specific communities: law experts, politicians, experts in social sciences, and robotics stakeholders. The main perspective of this course has at its core the application of human intelligence in the development of robots as ethical artificial entities. Specific objectives are: to understand ethical issues in robot development, as human artefacts receiving human experience; to present an inclusive perspective on "robotic"-type devices, with a general development perspective from Cyber-Physical-Systems (CPS) and System of Systems (SoS), to explain complexity issues; to approach the ethics of the artificial using AI based on electronic institutions; to explain ethical development in robotic engineering; to understand what designing with computational intelligence in robotic systems represent.

C42: Scientific Research, Practice and Dissertation project

The course assists the master students in applying in practice the knowledge, activities and results of the scientific research they performed during three semesters. The dissertation themes are related to the tasks specific to the research projects currently performed under the direction of teaching staff members of the 'Robotics and Automation' master program. For each theme there are defined objectives and performance indicators that must be realized during the preparation of the dissertation project. The teaching staff members of the RA courses propose dissertation themes to the master students. The master students select their dissertation themes and work them out: develop conceptual solutions and justify the selected solution, develop the functional model, design and implement system architectures, control schemes, control algorithms and programs using novel, efficient hardware si software technologies.