CHAPTER B: SPECIFIC TERMS FOR THE INTERDEPARTMENTAL POSTGRADUATE PROGRAM OF STUDIES (IPPS)

“AUTOMATION SYSTEMS (AS)”

Article 18

“Structure of the IPPS”

1. The School of Mechanical Engineering in collaboration with the Schools of Naval Mechanical Engineering, Electrical and Computer Engineering, Chemical Engineering, Mining & Metallurgical Engineering, Applied Mathematics and Natural Sciences of the National Technical University of Athens (NTUA) organize and operate from the academic year 2018- 2019 the Interdepartmental Postgraduate Program of Studies (IPPS) in the scientific field “Automation Systems” in accordance with the provisions of Law 4485/2017 (Government Gazette 114 Α΄).

2. The School of Mechanical Engineering undertakes the administrative support of the program.

Article 19

“Subject area and purpose of the program”

1. The subject of the program Automation Systems covers the areas of:

    I. Manufacturing and Production Systems, and

    II. Automatic Control Systems and Robotics.

2. The purpose of the IPPS is to strengthen the scientific and technological research in the area of Manufacturing and Production Systems and Automatic Control and Robotics Systems, and to produce new knowledge in these areas. It is sought to specialize its students in the modern methods and techniques of the interdisciplinary approach of cooperation and research in the area of Automation Systems, and to connect the educational and research processes of the IPPS with the industry, with the ultimate goal of contributing to the technological development of Greece.

3. The expected learning outcomes are proficiency in analysis, design, and innovation in the areas of Manufacturing and Production Systems and Automatic Control and Robotics Systems, according to the European and National Higher Education Qualifications Framework level 7. With the qualification acquired by successfully following the program, its graduates can successfully meet the growing needs of the country's Public and Private sector, and in general, and are able to produce new knowledge in the field of Automation Systems, as required by the modern needs of society and technological developments.

Article 20

“Postgraduate degree”

The IPPS awards a Diploma of Postgraduate Studies (Master’s Degree) in the area of Automation Systems after successful completion of the relevant course of studies, in the following directions**:**

Direction A: “Manufacturing and Production Systems” and Direction B: “Automatic Control and Robotics Systems”. The type of Diploma of Postgraduate Studies is indicated below in the Greek language and in the English language and is issued under the responsibility of the Director of the IPPS, with the administrative support of the School of Mechanical Engineering and with the assistance of the IT Department of NTUA.

Article 21

“Duration of studies”

The minimum duration of studies in the IPPS “Automation Systems” (A.S.) is three (3) academic semesters of minimum duration of 13 weeks each. The maximum duration of study is two (2) years. See also Article 11 of this regulation.

Article 22

“Language of Instruction”

The language of instruction in the IPPS “Automation Systems” is English, therefore a high level of proficiency of the English language is required for postgraduate students whose mother tongue is not English.

Article 23

“Curriculum”

To obtain the Master’s Degree, the following are required:

1. The attendance and successful examination in at least 12 courses which in total correspond to at least 60 European Credit Transfer and Accumulation System (ECTS) credits, and
2. The completion and successful examination of the Master’s Thesis equivalent to 30 ECTS credits. In the IPPS “Automation Systems” postgraduate students have the opportunity to attend a series of courses that can be distinguished into compulsory specialization courses, which are 2 per semester for each major, and elective specialization courses. The latter, for direction A, are four out of seven (7) in the first semester and four out of eight (8) in the second semester, while for direction B, they are three out of five (5) in the first semester and three out of five (5) in the 2nd semester, while two (2) courses from the A Direction must be chosen as an option.

3. Each IPPS course is 3 teaching hours long and corresponds to 5 ECTS. Each postgraduate student attends the 2 compulsory courses of specialization to which he has been admitted (ECTS = 2 × 5 = 10). Compulsorily chooses at least 4 of the elective specialization courses (ECTS = 4 × 5 = 20) 3. The redistribution of courses in the IPPS will be done by decisions of the competent bodies. The possibilities and limitations of course selections are specified in the IPPS AS Study Guide. Table 1 provides the titles of the courses, the description of the courses and the corresponding credits.

Table 1. Compulsory and optional compulsory specialization courses.

Direction A: "Manufacturing and Production Systems"

TABLE OF COMPULSORY COURSES					
Courses Semester A		**ECTS**	**Courses Semester B**		**ECTS**
1108	Modelling and Control of Dynamical Systems	5	1106	CAM and Applications	5
1107	Design of Control Systems	5	2206	Sensors	5
TABLE OF ELECTIVE COURSES (*Mandatory selection of 4* ***courses per semester***)					
Courses Semester A		**ECTS**	**Courses Semester B**		**ECTS**
1101	Optimal Product and System Design	5	1201	Transportation Systems	5
1103	Industrial Installations	5	1202	Antipollution Processes and Techniques	5
1104	CAD and Applications	5	1203	Welded Structures	5
1105	CAE and Applications	5	1204	Electrical-Mechanical Installations	5
1109	Technologies & Applications of Additive Manufacturing/3D Printing	5	1205	Polymer Technology	5
1110	Advanced Manufacturing Systems (CIM-INDUSTRY 4.0)	5	1207	Energy Systems in Building and Industry	5
1206	Smart Materials	5	2204	Mechatronic Systems	5
			2103	Measurements	5
Total semester ECTS		30	Total semester ECTS		30
Semester C			**ECTS**		
Master's Thesis Preparation			**30**		

Direction B: “Automatic Control and Robotics Systems”

Courses Semester A		ECTS	Courses Semester B		ECTS
1108	Modelling and Control of Dynamical Systems	5	2202	Nonlinear Control Systems	5
2104	Robot Control Systems	5	2205	Robotics Laboratory	5
TABLE OF ELECTIVE COURSES **From Direction A:** *Mandatory Selection of **2** courses **in total**, i.e., either **1** per term, or **2** in either of the 2 semesters taken from the Direction A courses as they appear in the table above and are not included in this table.* **From B΄ Direction:** *Mandatory Selection of **3** courses per semester.*					
Courses Semester A		**ECTS**	**Courses Semester B**		**ECTS**
1109	Technologies & Applications of Additive Manufacturing/3D Printing	5	2103	Measurements	5
1206	Smart Materials	5	2204	Mechatronic Systems	5
2201	Multivariable Control Systems	5	2206	Sensors	5
2203	Intelligent Control and Robotic systems	5	2207	Adaptive, Robust and Hierarchical Control	5
2109	Seminar Course in Automatic Control and Robotics - 1	5	2209	Seminar Course in Automatic Control and Robotics - 2	5
Total semester ECTS		30	Total semester ECTS		30
Semester C			**ECTS**		
Master's Thesis Preparation			30		

Article 24

“Number of admitted postgraduate students”

The maximum number of graduate students admitted to the IPPS “Automation Systems” is set at sixty (60), except for the exceptions provided for in Article 7 of these Regulations. The total number of postgraduate students admitted each year in the IPPS is determined by the Postgraduate Studies Committee according to the number of teaching staff in the IPPS and the student-to-faculty ratio, the technical infrastructure and the classrooms.

Article 25

“Organization of the educational process”

It includes live teaching or the use of modern distance education methods either entirely or partially.

Article 26

“Infrastructure”

The necessary infrastructure, such as classrooms, laboratories, and computers, is provided by the collaborating Schools. Indicatively, the Laboratories of the Coordinating School and the collaborating Schools are mentioned as follows:

The **School of Mechanical Engineering** has sufficient teaching staff and laboratory infrastructure for the operation of the IPPS based on its human resources and infrastructure as recorded in its six (6) Sectors:

- Industrial Management & Business Research Sector
- Heat Sector
- Mechanical Constructions & Automatic Control Sector
- Nuclear Technology Sector
- Liquids sector
- Manufacturing Technology Sector

The Sector of Industrial Management & Operational Research has 7 faculty members, 2 laboratory teaching staff members, 1 specialized technical laboratory staff member and 5 Laboratories

- Production Organization Laboratory
- Study of Business Research
- Decision Support Laboratory (non-statutory)
- Metrology Laboratory
- Production Organization Study

The Sector of Heat has 7 faculty members, 2 laboratory teaching staff members, 1 specialized technical laboratory staff member and 8 Laboratories

- Steam Engines and Boilers Laboratory
- Laboratory of Heterogeneous Mixtures & Combustion Systems
- Laboratory of Applied Thermodynamics
- Solar Technology Laboratory
- Thermal Processes Laboratory
- Heat Transfer Laboratory
- Internal Combustion Engines Laboratory (IEC)
- Refrigeration Technology Laboratory of Refrigerator Vehicles
- Refrigeration and Air Conditioning Laboratory

The Sector of Mechanical Constructions & Automatic Control has 8 Faculty members, 2 laboratory teaching staff members, 4 specialized technical laboratory staff members and 6 Laboratories

- Laboratory of Automatic Control and Regulation of Machines & Installations

- Dynamics and Structures Laboratory
- Biomechanical and Systems Biology Laboratory (non-institutionalized)
- Vehicle Laboratory
- Machine Components Laboratory
- Rapid Prototyping & Tooling Workshop

The Sector of Nuclear Technology has 4 faculty members, 1 laboratory teaching staff member, and 2 laboratories

- Nuclear Technology Laboratory
- Laboratory of Measurements of Technical Quantities

The Sector of Fluids has 10 faculty members, 5 laboratory teaching staff members, 1 specialized technical laboratory staff member and 5 Laboratories

- Aerodynamics Laboratory
- Laboratory of Biofluid Engineering & Biomedical Technology
- Thermal Turbines Laboratory
- Environmental Protection Technological Innovations Laboratory
- Laboratory of Hydrodynamic Machines

The Manufacturing Technology Sector has 4 faculty members, 1 laboratory teaching staff member, 1 specialized technical laboratory staff member and 1 Laboratory

- Materials Processing Laboratory (Mechanical & Engineering Factory)

Additionally, the School of Mechanical Engineering maintains a computer room (PC LAB) and has a fully equipped classroom (Z102) for teaching the courses of the Interdepartmental Postgraduate Program.

As evident from the above, the School of Mechanical Engineering possesses both the staff and the educational/research structures necessary to support the postgraduate study programs it coordinates.

The **School of Electrical and Computer Engineering** has sufficient teaching staff and laboratory infrastructure for the operation of these postgraduate programs based on its human resources and infrastructure as recorded in its seven (7) Sectors and their laboratories which are:

- Biomedical Optics and Applied Biophysics
- Electron Beam, Plasma and Non-Linear Optics
- Electronic Materials and Nanoelectronic Devices
- Wireless and Long-Distance Communication
- Biomedical Technology
- Biomedical Simulations and Imaging Technology (*)
- Intelligent Communications and Broadband Networks (*)
- Electrical Materials
- Microwave and Fibre Optics
- Radar and Remote Sensing Systems (*)

- Photonic Communications (*)
- Computer Vision, Speech Communication and Signal Processing (*)
- Robotics and Automation
- Automatic Control Systems
- Natural Language Processing (*)
- Intelligent Systems, Content, and Interaction
- Logic and Computing Science (*)
- Microcomputers and VLSI Digital Systems
- Personal Computers (*)
- Knowledge and Data Base Systems
- Artificial Intelligence and Learning Systems
- Software Technology
- Computer Systems
- Management and Optimal Planning of Telematics Networks
- Computer Networks
- Simulation of Communication Networks (*)
- Multimedia Communications and World Wide Web Technologies (*)
- Electronics
- Electronic Sensors
- Mobile and Personal Communications (*)
- Protocol Specification (*)
- Multimedia Technology
- Telecommunication Systems
- Electric Machines and Power Electronics
- Electrical Machine Control Systems (*)
- Electricity Systems
- Energy-Economy-Environment Models (*)
- High Voltage (*)
- High Voltage and Electrical Measurements
- Photography (*)
- Decision Support and Management Systems

*not established

As evidenced from the above, the School of Electrical & Computer Engineering has both the staff and the educational/research structures necessary to support the postgraduate programs in which it participates.

Similarly, the **School of Naval Architecture and Marine Engineering** has sufficient teaching staff and laboratory infrastructure for the operation of this postgraduate program based on its human resources and infrastructure as recorded in its four (4) Sectors and their respective laboratories:

- Ship Study Laboratory
- Maritime Transport Laboratory (by decision of the Senate)
- Nautical & Marine Hydrodynamics Laboratory
- Marine Engineering Laboratory
- Shipbuilding Technology Laboratory

- Laboratory of Floating Structures & Anchoring Systems

The School of Naval Architecture and Marine Engineering also has a Personal Computing Laboratory.

As indicated above, the School of Naval Architecture and Marine Engineering possesses both the personnel and the educational/research structures necessary to support the postgraduate programs in which it participates.

The **School of Mining & Metallurgical Engineering** also has sufficient teaching staff and laboratory infrastructure for the operation and participation in these Interdepartmental Master's Degree Programs based on its human resources and relevant facilities, as documented in its three (3) Sectors and their laboratories which are:

- Metal workshop
- Metallurgical Laboratory
- Mineral Enrichment Laboratory
- Laboratory of Environmental Protection Science and Technology in Metallurgy & Materials Technology
- Laboratory of Computational Rheology and Processing of Plastic and Composite Materials
- Laboratory of Mining Technology and Environmental Mining
- Rock Mining Laboratory
- Laboratory of Applied Geophysics
- Tunnelling Technology Laboratory
- Laboratory of Mineralogy - Petrology - Depositology
- Geology Laboratory
- Laboratory of Technical Geology & Hydrogeology

As evidenced by the above, the School of Mining & Metallurgical Engineering has both the staff and the educational/research structures necessary to support the Interdepartmental Postgraduate Programs of Studies in which it participates.

The **School of Chemical Engineering** has adequate teaching staff and laboratory infrastructure for the operation of these postgraduate programs based on its human resources and infrastructure as recorded in its four (4) Sectors and these laboratories which are:

- General Chemistry Laboratory
- Laboratory of Inorganic and Analytical Chemistry
- Laboratory of Organic Chemistry
- Laboratory of Industrial and Energy Economy
- Laboratory of Thermodynamics and Transport Phenomena
- Chemical Process Engineering Laboratory
- Process Design and Analysis Laboratory
- Physical Chemistry Laboratory
- Materials Science and Technology Laboratory

- Laboratory of Advanced & Composite Materials, Nanomaterials, Nanoprocesses & Nanotechnology
- Inorganic Materials Technology Laboratory
- Biotechnology Laboratory
- Polymer Technology Laboratory
- Laboratory of Fuels and Lubricants Technology
- Food Chemistry and Technology Laboratory
- Laboratory of Organic Chemical Technology

The School also includes the Horizontal Laboratory for Control and Quality of Processes and Products. Additionally, the School of Chemical Engineering has classroom 26 for teaching the IPPS Automation Systems course.

As evidenced by the above, the School of Chemical Engineering has both the staff and the educational/research structures necessary to support the postgraduate study programs in which it participates.

The **School of Applied Mathematics and Natural Sciences (SEMFE)** has sufficient teaching staff and laboratory infrastructure for the operation of these postgraduate programs based on its human resources and infrastructure as recorded in its four (4) Sectors and their laboratories which are :

- Physics Laboratory
- Optical Laboratory
- Laboratory of Atomic and Molecular Physics
- Physical Condensed Matter Laboratory
- Laboratory of Optoelectronics and Laser Physics - Technology
- Laboratory of Nuclear Physics and Elementary Particles
- Materials Laboratory
- Strength of Materials Laboratory
- Laboratory of Applied Mechanics and Photoelasticity
- Laboratory of Theoretical and Applied Philosophy, History and Sociology of Science and Technology
- Laboratory of Theoretical and Applied Economics and Law
- Laboratory of Algorithmic Applications and Logic
- Statistics Laboratory
- Computational Mathematics and Mathematical Modelling Laboratory
- Economic Mathematics and Mathematical Optimization Laboratory
- Study of Higher Mathematics

As evidenced by the above, SEMFE possesses both the personnel and the educational/research structures that are necessary to support the IPPS in which it participates.

The Program of Studies Committee proposes to the competent bodies of the NTUA the necessary measures to strengthen this infrastructure and to find the necessary resources for the acquisition of new or the renewal of the existing technical infrastructure of the IPPS.

Article 27

“Funding sources”

It includes indicatively

- NTUA’s budget
- Budget Ministry of Education, Religious Affairs and Sports
- Donations, benefits, legacies, sponsorships
- Resources from research projects
- Resources from programs of the European Union or other international organizations
- Revenues of the Special Account of NTUA research funds
- Tuition fees from non-EU students

Article 28

“Diploma Type”

HELLENIC REPUBLIC

THE NATIONAL TECHNICAL UNIVERSITY OF ATHENS

BY RECOMMENDATION

OF THE PROGRAMME STUDIES COMMITTEE

OF THE INTEDISCIPLINARY POSTGRADUATE PROGRAMME

“AUTOMATION SYSTEMS”

UNDER THE COORDINATION OF THE SCHOOL OF MECHANICAL ENGINEERING

AND THE PARTICIPATION OF THE SCHOOLS OF

APPLIED MATHEMATICAL AND PHYSICAL SCIENCES

OF ELECTRICAL AND COMPUTER ENGINEERING,

OF MINING & METALLURGICAL ENGINEERING

OF NAVAL ARCHITECTURE AND MARINE ENGINEERING,

AND OF CHEMICAL ENGINEERING,

OF THE NTUA

AWARDS TO

…

who in (month, year), fulfilled all the academic requirements

DIPLOMA OF POSTGRADUATE STUDIES

MASTER OF SCIENCE

IN THE SCIENTIFIC FIELD OF

“AUTOMATION SYSTEMS”

IN THE DIRECTION OF (1)

“…”

WITH THE GRADE “GOOD / VERY GOOD / EXCELLENT”

Athens, Greece, (date)

The Director of the Postgraduate Programme The Secretary of the School of Mechanical Engineering The Rector

(1) It is mentioned at the discretion of the Programme Studies Committee

Article 29

“Transitional provisions”

1. Postgraduate students who have been admitted to the program until the academic year 2022-2023 will complete their studies in accordance with the provisions of the previous decision of the Senate 9/5/2018 (4th Session).
2. Any issues not provided for in this decision shall be regulated by the competent bodies in accordance with the applicable legislation.
3. This decision shall be published in the Government Gazette.

APPENDIX B

COURSE CONTENT

OF “Automation Systems”

Content of specialization courses A: Manufacturing and Production Systems

Compulsory Courses 1st Semester

1107 Design of Control Systems and Laboratory

Introduction to SAE. Signals, sensors, effectors. Part A: Introduction to optimal control: Pontryagin, optimal quadratic regulator-LQ, Riccati equation. Optimal controller design. Observers. Part B: Design of control systems using the Model Predictive Control (MPC) method. The control function of the two stages is explained: estimation of future state values and optimization over the future control horizon. Consideration of factors such as Single Input-Single Output (SISO) and Multi-Input Multi-Output (MIMO) systems, constraints imposed on controlled and control variables, systems with delays. A distinction is made between cases without restrictions, where the control function is close to that of the optimal quadratic regulator (LQR) and the case with limitations, where a real-time optimization problem is solved. The method includes a system model, so appropriate forms of mathematical models and system identification methods are presented. Basic design and analysis are done in the time domain (continuous and discrete). MATLAB/Simulink and Control Systems & Model Predictive Control toolbox are used in examples and applications. There is mandatory LQ/MPC controller design work in a laboratory configuration with STM32 Nucleo F401 & MATLAB/Simulink microcontroller.

1108. Modelling and Control of Dynamical Systems

Methods of Modeling Dynamic Systems: This section presents the basic characteristics of dynamic systems and the mathematical tools used to model them, such as transfer functions, state-space representation, and Bode plots. It also presents methodologies for converting dynamic modeling from one form to another and methods for computing the dynamic response of systems to various inputs or disturbances.

Stability-Controllability-Observability: This section focuses on the concepts of stability, controllability, and observability, and the mathematical tools used to explore these properties in dynamic systems.

Characteristics of Dynamic Systems: Characteristics and criteria for stability and performance of control systems are presented in the time domain (such as rise time, overshoot, response time) and in the frequency domain (such as Bode and Nyquist diagrams and criteria, gain and phase margins, crossover frequency, peaks of frequency response and sensitivity).

Design of Control Systems that Meet Stability and Performance Specifications: The importance and modeling of feedback in the design of control systems are presented, along with a range of design methodologies that start with a brief review of classic methods such as Ziegler-Nichols and Cohen-Coon and extend to advanced methodologies like Internal Model Control (IMC), direct synthesis, and loop shaping.

Standardization of Uncertainty and Criteria for Robust Stability and Performance: Methods for quantifying uncertainty and incorporating it into the formulation and application of robust stability and performance criteria are presented. Students are also trained in the design of controllers that meet these criteria based on the methodology of mixed sensitivity.

System Norms and H2, H_∞ Control Methods: The H2, H_∞ control methods are presented based on the definition of norms, starting with vector norms and extending to matrix, signal, and system norms. Emphasis is given to explaining the theory and the mathematical optimization problems formulated for each method. The methodology of Singular Value Decomposition (SVD) and its importance in the analysis and design of control systems for multivariable dynamic systems are also presented.

Optimal Control: The methodologies of Linear Quadratic Regulator (LQR) and Linear Quadratic Gaussian (LQG) as specific cases of the H2 method are presented in detail. Emphasis is given to a specific methodology for calibrating LQR controllers that ensures good performance of the closed-loop system for multivariable systems. Finally, an introduction to Model Predictive Control (MPC) methodologies is provided, which are based on the discretization of dynamic systems and the incorporation of the problem's constraints into the objective function of the mathematical optimization problem solved in real time.

ELECTIVE COURSES

1101. Optimal Project Design

Introduction to Engineering Design – Systematic Approach of Engineering Design. / Systematic conception of the structure. Decomposition of a structure into elements. Concurrent Engineering (CE) – Existing methods and tools of CE. / CE in optimal structural design. / Alternative Designs / Optimization in Product Design.

1103. Industrial Installations

Signal Theory:

- Basics of signals. Analog, discrete, and digital signals.
- Convolution, auto-correlation, and cross-correlation of signals.
- Modulated signals: amplitude, phase, and frequency modulation.
- Time windows.

- Time and statistical signal indicators.
- Sampling Theorem. Aliasing. Sampling parameters: scale factors (acceleration, velocity, and displacement), amplitude (Peak-to-Peak, RMS, etc.), number of samples and sampling period.
- Leakage and clarity in the time and frequency domains.

Vibrations and Fault Diagnosis:

- Maintenance Strategies: Corrective, preventive, and predictive maintenance.
- Introduction, basic concepts, fault isolation and identification.
- Vibration sensors (accelerometers, velocity sensors, etc.).
- Measurement and standards of vibration analysis.
- Calculation of basic fault frequencies.
- Diagnosis of faults in rotating machines with constant speed: basic concepts.
- Analysis/study of basic electromechanical faults: unbalance, misalignment, resonance, mechanical looseness, cavitation, faults in bearings and gears, and faults in induction motors.

Processing of Time Signals and Frequency Analysis:

- Processing of time signals and frequency analysis, Fourier series, and signal spectrum.
- Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT).
- Properties and limitations of the Fourier transform.
    - Advanced signal processing methods for fault diagnosis in the time domain, frequency domain, and time-frequency domain: Signal demodulation (Envelope Analysis) using the Hilbert transform., Morphological Analysis, Short-Time Fourier Transform (STFT), Wavelet Transform.

Artificial Intelligence (AI) and Machine Learning (ML):

- Introduction to AI and ML.
- Differences between Machine Learning and Deep Learning.
- Supervised and unsupervised learning.
- ML for data and condition classification.
- Extraction/computation of features in the time domain (kurtosis, skewness, RMS, power, etc.), frequency domain (spectral kurtosis, spectral range, spectral mean, permutation entropy, etc.), and time-frequency domain.
- Properties of appropriate features. Standardization and normalization of features/data.
- Methods of selection (e.g., CDET-compensation distance evaluation technique) or reduction (e.g., PCA) of the number of features.
- Eigenvectors, eigenvalues, eigenvalue diagram, scree diagram, score, and loading diagram.

- Unsupervised Machine Learning methods: K-means, method analysis/study, proximity/similarity distances (e.g., Euclidean distance), random or non-random centroid selection. Advantages and disadvantages. Applications in the Matlab computational environment.
- Supervised Machine Learning methods: Support Vector Machines - SVM, method analysis/study, Kernel functions, and study of linear and non-linear classification. Advantages and disadvantages. Applications in the Matlab computational environment.
- Applications of Automated Data/Fault Classification.

Laboratory Demonstration Exercise:

The laboratory includes a demonstration of a small-scale experimental application related to fault diagnosis in a rotating machinery simulator of faults. Laboratory equipment (sensors, data recorders, etc.) is used to measure vibrations generated by the rotating machine. The specialized LabVIEW software used for designing information system architecture is presented and analyzed. Vibrations are recorded and analyzed in the time and frequency domains using Fast Fourier Transform (FFT). Additionally, data is processed using an envelope analysis method that uses the Hilbert transform. Differences in the spectrum for acceleration and velocity are studied.

Project/Research:

The project involves designing and developing an algorithm that simulates an automated fault classification system. Data (signals) recorded in an experimental setup in conditions of good operation, outer ring bearing wear, and inner ring bearing wear are used. The algorithm is developed in the Matlab or Python computational environment. The algorithm includes feature extraction using signal processing methods, normalization or not of features, selection or reduction of features, training a classifier using Machine Learning methods, and checking the performance of the final code using test signals. In case the number of training signals for an 'operational condition' is limited, affecting the classifier's performance, there is the possibility of increasing them by applying a simulation model of these signals.

1104. CAD & Applications

Introduction. Bézier, B-spline, and NURBS curves and surfaces. Algorithms de Casteljau, de Boor, degree elevation, subdivision, and knot insertion. Geometric continuity between segments of curves/surfaces. Surfaces of quadrilateral, triangular, and mixed topology. Offset curves and surfaces. The course aims to provide basic knowledge and develop fundamental skills in the area of computer-aided design. The foundational knowledge pertains to the structure of the geometric core of a modern CAD system and the methodologies and techniques of its development. Skills are cultivated through training students in a typical commercial CAD system and assigning them the completion of a design project for industrial objects of small/medium complexity within this system.

1105. CAE & Applications

The course includes Generalization of the Finite Element Method, Methods of Weighted l Residuals, Shape Functions in Finite Elements, Construction of shape functions, Shape functions in one-dimensional domains, Shape functions in two-dimensional domains, Plane elements, Beam elements, General element families, Mapped elements, Isoparametric mapping, Numerical integration.

The course aims to familiarize the students with the computational design of Mechanical Systems and the application of the methods through a project of their choice (after consultation with the instructor).

1206. Smart Materials

The course includes:

1. Definition and classification of smart materials and systems.
2. Correlation of microstructure with intelligent behaviour of materials.
3. Piezoelectric and Electrostrictive Materials.
4. Magnetostrictive materials.
5. Shape Memory Alloys and Magnetic Shape Memory Materials.
6. Electrorheological and magnetorheological fluids.
7. Technology of sensors, actuators and converters based on smart materials.
8. Main technological applications of smart materials.

1109. Technologies & Applications of Additive Manufacturing/3D Printing

The course includes the following:

- Historical evolution of relevant technologies, distinction, categorization, main technologies
- Steps of the overall AM/3D Printing process
- Feedstock materials & selection between available technologies & systems
- Relevant international standards, file types/protocols for AM, 3D Printing software
- Combination with other relevant/complementary modern digitally supported technologies & processes
- Tooling preparation, assistance of industrial production
- Major and secondary utilization & application fields, impact on modern technical operations, possibilities, and perspective of exploitation in the local technical and business environment
- Application examples

Within the context of this course, 3D printing software preparation exercises, as well as use of desktop FFF/FDM 3D Printers are performed, leading to a graded personally submitted field-oriented essay. Also, semester-long projects contributing to the overall grade are electively assigned to student groups of three.

1110. Advanced Manufacturing Systems (CIM-INDUSTRY 4.0)

- Typology and structure of manufacturing systems. Modern Manufacturing Systems: flexible, reconfigurable, and intelligent. Typical structure: machine tools, robots, sensors, mechatronic systems, controllers, databases, knowledge bases, local networks.
- Flexible Manufacturing System Control based on Petri Nets: classic, timed, coloured. Fundamental theory and applications in discrete event control.
- Integrated Manufacturing Systems (CIM) and their functional units. Information flow between functional units. Information interfaces. Main notions of networks: OSI model. Main notions of databases: generalized conceptual schema.
- Introduction to Industry 4.0 philosophy and technologies: Cyber-physical systems, Digital twins, Internet of Things, Virtual Reality, Machine Learning. Application domains: manufacturing process setup, process monitoring, tool / machine condition monitoring, Manufacturing Execution System – MES level.

Compulsory Courses 2nd Semester

1106. CAM & Applications

The course deals with the technology and programming of modern machine tools. Machine tool structure and basic subsystems. Main concepts of machine tool dynamics. Main concepts of CNC systems (interpolation, axes motion control systems). Manufacturing cells and DNC controllers. G-code programming for turning and machining centers, bending and 3D printing (toolpath calculation, data flows, CAD file transfer, post-processors). CAPP (generative and variant process plans, design and drafting using process morphological features). Industrial robot programming (on and offline) for machine tool tending and processing. Evaluation of machine tool and industrial robot accuracy using laser interferometer (principles and implementation).

2206. Sensors

- Basic principles of sensors: sensitivity, uncertainty, hysteresis, linearity, parameters affecting the sensor response, sensor characterization techniques, Laboratories of Testing and Calibration.

- Physical & chemical phenomena, used for sensor operation: phenomena in conducting, semiconducting, dielectric, magnetic and superconducting materials.
- Sensors: Mechanical sensors (displacement, position, velocity, acceleration, flow, force, tensile & compressive stresses, pressure), electric-magnetic sensors (electric current, electric field, magnetic field, magnetic anomaly detection), thermodynamic sensors (temperature, humidity, moisture), chemical sensors (ISFET).
- Sensor applications: energy & environment, health, safety & security, defence, industrial applications, system automation, domestic applications etc.

Lab:

1. Calibration of a Hall sensor
2. Magnetic sensors for position and field measurements
3. Arduino and applications (Part A)
4. Arduino and applications (Part B).

ELECTIVE COURSES

1201. Transportation Systems

Transportation systems – Modeling of transportation systems – Transport Economics. / Freight Transport – Road & Railway transport – Statistics. / Safe transportation of dangerous goods (ADR, RID, IMDG). / Green & Intelligent transport. / State of the art in vehicles technology.

1202. Antipollution Processes and Techniques

The course covers the following:

- Policy framework for the management of waste
- Sources, classification, and characteristics of waste
- Reuse repair recycling circular economy symbiosis concepts and examples
- Sorting, temporary storage and transportation of waste & examples,
- Biological treatment of waste & case studies
- Thermal Treatment of waste & case studies
- Hazardous waste management and disposal of waste

Field trip to an existing waste management facility

1203. Welded Structures

- Basic principles of welding Metallurgy.
- Welding thermal cycle and relevant metallurgical phenomena (welding zones, phase

transformations, microstructure evolution etc.) and residual stresses.

- Arc welding techniques (e.g., TIG, MIG), beam welding (laser, electron beam) and solid-state welding methods/techniques (e.g. friction stir, ultrasonic, diffusion).
- Protective atmosphere, available protection means (gasses, powders, slags etc.)
- Current and voltage, main equipment & techniques
- Main welding defects and non-destructive testing techniques, weldment control
- Health & safety

1204. Electrical-Mechanical Installations

Building insulation, design of heating-cooling systems, ventilation, water supply systems, sanitation systems, elevators and lifting machines, electrical installations.

1205. Polymer Technology

This course includes the presentation of basic concepts related to Polymer Technology. A brief reference is made on the synthesis processes and physicochemical characteristics (thermal transitions, crystallinity) of polymers. A presentation of the basic principles which control the rheology/rheometry of polymer melts follows, as well as of the moulding procedures, with special emphasis on the recommended operating conditions for polymer processing and their optimization. Finally, through some Case Studies, various modern applications are investigated in the field of biomedical polymers, nanostructured polymers, and food packaging. Reference is also made to some types of “smart polymers” suitable for applications as sensors/actuators.

1207. Energy Systems in Building and Industry

(a) Introduction; (b) Building Energy Systems (MEPs, Automation Systems, Metering, Energy Saving measures, Visit/measurements in a pilot building); (c) Energy Systems in Industry (Combustion Technologies, Cogeneration Heat/Electricity, Auxiliary Industrial Systems, Case Studies); (d) Heat/Electricity Storage (Systems and Applications)

2204. Mechatronics Systems

Introduction, design, modeling, parameter identification & analysis, sensors, actuators, mechanisms, transmissions, analog electronics, A/D & D/A, microcontrollers (h/w & s/w), single board computers, real-time PLC (RTOS), control, construction issues. The course aims to familiarize the students with the design of Mechatronic Systems and the application of the methods through a project of their choice (after consultation with the instructor).

2103. Measurements

Brief reference to the history of measurement. Structure and organization of modern metrology. Error Analysis, instrumentation, classical electric measurement methodology, oscilloscopes, nullifying instruments (bridges and compensation apparatus). Energy and power measurement of one-phase and multi-phase systems. Open loop and closed loop amplifiers, operational amplifiers, measurements on operational amplifiers. Analogue measurements of electrical quantities, digital multimeter (voltmeter, ammeter, ohmmeter), analogue measurements of non-electrical quantities, converters, force and torque measurement. Theoretical and statistical foundation of uncertainty. The assessment of uncertainties in practice. Measurement – Uncertainty – Decision rule.

Content of specialization courses B “Automatic Control and Robotics Systems”

Compulsory Courses 1st Semester

1108. Modelling and Control of Dynamical Systems

Methods of Modeling Dynamic Systems: This section presents the basic characteristics of dynamic systems and the mathematical tools used to model them, such as transfer functions, state-space representation, and Bode plots. It also presents methodologies for converting dynamic modeling from one form to another and methods for computing the dynamic response of systems to various inputs or disturbances.

Stability-Controllability-Observability: This section focuses on the concepts of stability, controllability, and observability, and the mathematical tools used to explore these properties in dynamic systems.

Characteristics of Dynamic Systems: Characteristics and criteria for stability and performance of control systems are presented in the time domain (such as rise time, overshoot, response time) and in the frequency domain (such as Bode and Nyquist diagrams and criteria, gain and phase margins, crossover frequency, peaks of frequency response and sensitivity).

Design of Control Systems that Meet Stability and Performance Specifications: The importance and modeling of feedback in the design of control systems are presented, along with a range of design methodologies that start with a brief review of classic methods such as Ziegler-Nichols and Cohen-Coon and extend to advanced methodologies like Internal Model Control (IMC), direct synthesis, and loop shaping.

Standardization of Uncertainty and Criteria for Robust Stability and Performance: Methods for quantifying uncertainty and incorporating it into the formulation and application of robust stability and performance criteria are presented. Students are also trained in the design of controllers that meet these criteria based on the methodology of mixed sensitivity.

System Norms and H2, H_∞ Control Methods: The H2, H_∞ control methods are presented based on the definition of norms, starting with vector norms and extending to matrix, signal, and system norms. Emphasis is given to explaining the theory and the mathematical optimization problems formulated for each method. The methodology of Singular Value Decomposition (SVD) and its importance in the analysis and design of control systems for multivariable dynamic systems are also presented.

Optimal Control: The methodologies of Linear Quadratic Regulator (LQR) and Linear Quadratic Gaussian (LQG) as specific cases of the H2 method are presented in detail. Emphasis is given to a specific methodology for calibrating LQR controllers that ensures good performance of the closed-loop system for multivariable systems. Finally, an introduction to Model Predictive Control (MPC) methodologies is provided, which are based on the discretization of dynamic systems and the incorporation of the problem's constraints into the objective function of the mathematical optimization problem solved in real time.

2104. Robot Control Systems

The main objectives of the course are: a) to introduce the students to the basic concepts and topics of Robotics, mainly regarding the analysis and control of classic robotic manipulators, systems which are widely used in a variety of industrial (and other) applications, and b) to familiarize the students with the analytical mathematical tools involved in the study of classical industrial robotic manipulation systems, as well as to help students assimilate and understand the functionalities and the control methods of a robotic system.

The contents of the course are organized in 3 main sections:

1) Kinematic Analysis of Robotic Manipulators
   - Forward and inverse kinematic analysis – Geometric model
   - Differential kinematic analysis – Forward and inverse – Jacobian matrix
   - Robotic manipulation systems with kinematic redundancies
2) Static and Dynamic Analysis of Robotic Manipulators
   - Study of forces and moments
   - Compliance matrix of a robotic manipulator
   - Newton-Euler and Lagrange formulations of robot dynamics
   - Direct and inverse dynamics
   - Robot dynamic parameter identification
3) Motion Control of Robotic Manipulation Systems
   - Robot trajectory design – Robot motion planning
   - Joint space linear control – Local joint PD control
   - Model-based nonlinear dynamic control; Computed-torque control
   - Operational space control
   - Adaptive and Robust control of robotic systems

ELECTIVE COURSES

1107. Design of Control Systems and Laboratory

Introduction to SAE. Signals, sensors, effectors. Part A: Introduction to optimal control: Pontryagin, optimal quadratic regulator-LQ, Riccati equation. Optimal controller design. Observers. Part B: Design of control systems using the Model Predictive Control (MPC) method. The control function of the two stages is explained: estimation of future state values and optimization over the future control horizon. Consideration of factors such as Single Input-Single Output (SISO) and Multi-Input Multi-Output (MIMO) systems, constraints imposed on controlled and control variables, systems with delays. A distinction is made between cases without restrictions, where the control function is close to that of the optimal quadratic regulator (LQR) and the case with limitations, where a real-time optimization problem is solved. The method includes a system model, so appropriate forms of mathematical models and system identification methods are presented. Basic design and analysis are done in the time domain (continuous and discrete). MATLAB/Simulink and Control Systems & Model Predictive Control toolbox are used in examples and applications. There is mandatory LQ/MPC controller design work in a laboratory configuration with STM32 Nucleo F401 & MATLAB/Simulink microcontroller.

1110. Advanced Manufacturing Systems (CIM-INDUSTRY 4.0)

- Typology and structure of manufacturing systems. Modern Manufacturing Systems: flexible, reconfigurable, and intelligent. Typical structure: machine tools, robots, sensors, mechatronic systems, controllers, databases, knowledge bases, local networks.
- Flexible Manufacturing System Control based on Petri Nets: classic, timed, coloured. Fundamental theory and applications in discrete event control.
- Integrated Manufacturing Systems (CIM) and their functional units. Information flow between functional units. Information interfaces. Main notions of networks: OSI model. Main notions of databases: generalized conceptual schema.
- Introduction to Industry 4.0 philosophy and technologies: Cyber-physical systems, Digital twins, Internet of Things, Virtual Reality, Machine Learning. Application domains: manufacturing process setup, process monitoring, tool / machine condition monitoring, Manufacturing Execution System – MES level.

1206. Smart Materials

The course includes:

1. Definition and classification of smart materials and systems.
2. Correlation of microstructure with intelligent behaviour of materials.
3. Piezoelectric and Electrostrictive Materials.
4. Magnetostrictive materials.

5. Shape Memory Alloys and Magnetic Shape Memory Materials.
6. Electrorheological and magnetorheological fluids.
7. Technology of sensors, actuators and converters based on smart materials.
8. Main technological applications of smart materials.

1109. Technologies & Applications of Additive Manufacturing/3D Printing

The course includes the following:

- Historical evolution of relevant technologies, distinction, categorization, main technologies
- Steps of the overall AM/3D Printing process
- Feedstock materials & selection between available technologies & systems
- Relevant international standards, file types/protocols for AM, 3D Printing software
- Combination with other relevant/complementary modern digitally supported technologies & processes
- Tooling preparation, assistance of industrial production
- Major and secondary utilization & application fields, impact on modern technical operations, possibilities, and perspective of exploitation in the local technical and business environment
- Application examples

Within the context of this course, 3D printing software preparation exercises, as well as use of desktop FFF/FDM 3D Printers are performed, leading to a graded personally submitted field-oriented essay. Also, semester-long projects contributing to the overall grade are electively assigned to student groups of three.

2109. Seminar Course in Automatic Control and Robotics - 1

It is offered by invited lecturers after the recommendation of the Director of IPPS.

Compulsory Courses 2nd Semester

2202. Nonlinear Control Systems

Stability notions for dynamical systems. Lyapunov functions for dynamical systems. The state feedback stabilization problem for control systems. Backstepping for triangular nonlinear control systems. Control Lyapunov Functions and the Artstein-Sontag Theorem. Control Lyapunov Functions for nonlinear triangular control systems. Input-to-State Stability. The observer problem for control systems. The output feedback stabilization problem for control systems. High-Gain observer design for globally Lipschitz nonlinear systems.

2205. Robotics Laboratory

The main objectives of this course are to help students: 1) acquire practical knowledge and skills through laboratory exercises, and 2) assimilate the corresponding theoretical knowledge on motion planning, control and programming of robotic systems (mainly industrial-type robotic manipulators and robot-integrated automated production systems).

The laboratory exercises, for the practical understanding of the functionalities and control modes of robotic systems, include the following: 1) Linear control of a single robotic joint, 2) Programming of a robotic production process (robot cell), 3) Elements of linear and nonlinear control with application to articulated robot arms (such as the Pendubot, a two degree-of-freedom inverted pendulum setup), 4) Programming techniques for an industrial-type robot arm (e.g. Adept Scara-type), 5) Motion programming of a small collaborative robot arm (a six degree-of-freedom Cobot) performing a pick-and-place task.

The contents of the course also include familiarization (through the preparation of a team project) with specialized programming tools for the development of software applications to perform motion planning and control of robotic systems using ROS (Robot Operating System) as the software platform

ELECTIVE COURSES

2103. Measurements

Brief reference to the history of measurement. Structure and organization of modern metrology. Error Analysis, instrumentation, classical electric measurement methodology, oscilloscopes, nullifying instruments (bridges and compensation apparatus). Energy and power measurement of one-phase and multi-phase systems. Open loop and closed loop amplifiers, operational amplifiers, measurements on operational amplifiers. Analogue measurements of electrical quantities, digital multimeter (voltmeter, ammeter, ohmmeter), analogue measurements of non-electrical quantities, converters, force and torque measurement. Theoretical and statistical foundation of uncertainty. The assessment of uncertainties in practice. Measurement – Uncertainty – Decision rule.

2204. Mechatronics Systems

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2206. Sensors

- Basic principles of sensors: sensitivity, uncertainty, hysteresis, linearity, parameters affecting the sensor response, sensor characterization techniques, Laboratories of Testing and Calibration.
- Physical & chemical phenomena, used for sensor operation: phenomena in conducting, semiconducting, dielectric, magnetic and superconducting materials.
- Sensors: Mechanical sensors (displacement, position, velocity, acceleration, flow, force, tensile & compressive stresses, pressure), electric-magnetic sensors (electric current, electric field, magnetic field, magnetic anomaly detection), thermodynamic sensors (temperature, humidity, moisture), chemical sensors (ISFET).
- Sensor applications: energy & environment, health, safety & security, defence, industrial applications, system automation, domestic applications etc.

Lab:

1. Calibration of a Hall sensor
2. Magnetic sensors for position and field measurements
3. Arduino and applications (Part A)
4. Arduino and applications (Part B).

2207. Adaptive, Robust and Hierarchical Control

Introduction to adaptive and robust control, Lyapunov stability theory, Lyapunov stabilizing controllers, model-based controllers, sliding mode robust control, model reference adaptive control (MRAC), Self-tuning regulators, introduction to hierarchical and decentralized control, open and closed-loop hierarchical control, nested hierarchical control, decentralized control of large scale systems.

2209. Seminar Course in Automatic Control and Robotics - 2

It is offered by invited lecturers after the recommendation of the Director of IPPS.