CENTRALE NANTES

ENGINEERING PROGRAMME

2024-2025

Year 2 / Year 3

Specialisation option

Energy Control and Management

OD ECONTROL

PROGRAMME SUPERVISOR
Mohamed Assaad HAMIDA

ENGINEERING - OD ECONTROL

Autumn Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 73	12	Core course	CONEN INFEM METOD SIMUS	Energy Conversion Chain Embedded computing Methodology of linear control Simulation of electrical systems
UE 74	13	Core course	CAVAN CONUM LTIOT ODAS P1ECONTROL	Advanced control Digital design on FPGA Low tech IoT Observation and diagnosis Project 1

Spring Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 83	14	Core course	GENER MCIA P2ECONTROL PENER TENER	Smart energy management Model checking and AI Project 2 Energy Project Role of electricity in the energy transition

Energy Conversion Chain [CONEN]

LEAD PROFESSOR(S): Mohamed Assaad HAMIDA

Requirements

Objectives

This course deals with the analysis and synthesis of the main structures of the energy conversion chain. For the sources part, the objective is to present a broad overview of the various conventional and renewable energy sources. For the static converters part, the aim is to understand the operation and to analyse the wave-forms of converters such as three-phase rectifiers, choppers and inverters. For the electrical machines part, the aim is to master the principle of electromagnetic conversion and to model synchronous and asynchronous machines in steady state.

Course contents

At the end of the course, students will be able to
- Understand the operation of different energy sources (renewable or conventional)
- Understand the operation of the different types of static converters and their uses in electrical energy systems.
- Know the different electrical actuators and their modelling.

Course material

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	14 hrs	8 hrs	8 hrs	0 hrs	2 hrs

Embedded computing [INFEM]

LEAD PROFESSOR(S): Mikael BRIDAY

Requirements

Objectives

This course explores embedded systems, subject to strict constraints and often integrated in critical environments such as avionics and automotive. In close interaction with processes, these systems require the implementation of control laws covered in other courses. Students will work at two levels of abstraction:
- with direct programming on embedded boards (bare metal);
- using a real-time operating system (RTOS) that offers higher level services;

In the latter case, multi-tasking programming and synchronization mechanisms between tasks are addressed.

Course contents

Direct programming on embedded boards:
- Representation of the information;
- Structure of a micro-controller board;
- Programming of parallel, analog inputs/outputs;
- Programming of integrated counters, of a PWM ;
- Interruptions (with associated synchronization problems).

Use of a RTOS:
- Functional decomposition of embedded systems;
- Software architecture of a control system;
- Synchronous and asynchronous implementation: role of the executive;
- Synchronization primitives, event and time management;
- Scheduling
- Examples of Real Time applications.

Course material

- D. Patterson & J. Hennessy, Computer Organization and Design – ARM Edition, Morgan Kaufmann, 2017
- Les systèmes d'exploitation temps réel - Techniques de l'Ingénieur R5080 et R5082 - J.P. Elloy Y. Trinquet

Assessment

Collective assessment: EVC 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	4 hrs	12 hrs	0 hrs	0 hrs

Methodology of linear control [METOD]

LEAD PROFESSOR(S): Guy LEBRET

Requirements

A first course in control is necessary is a prerequisite (typically the SiSCo course of the first year of Centrale Nantes)

Objectives

To define a control methodology for linear multi-input multi-output systems based on the state approach.

Course contents

- Introduction to the concepts of the state space approach, controllability, observability, pole placement using state feedback or estimated state feedback.
- How to obtain robust stability with loop transfer recovery technic
- How to explicitly introduce integral action.
- Description of the methodology and application to the SISO case (choice of poles).

Course material

Ph. de Larminat, 'Automatique, Commande des Systèmes Linéaires', Hermés
Ph. de Larminat, 'Le Contrôle d'Etat Standard', Hermés.
G. Lebret, 'Méthodologie de la Commande', Polycopié Centrale de Nantes.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	6 hrs	8 hrs	0 hrs	2 hrs

Simulation of electrical systems [SIMUS]

LEAD PROFESSOR(S): Mohamed Assaad HAMIDA

Requirements

Objectives

The objective of this course is to present the basic tools for the simulation of dynamic systems.

Course contents

The course starts with an introduction to numerical integration techniques, necessary for the simulation of dynamic systems. The course continues with the presentation of different software solutions: Matlab/Simulink, Amesim, ...

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	0 hrs	20 hrs	0 hrs	0 hrs

Advanced control [CAVAN]

LEAD PROFESSOR(S): Franck PLESTAN / Guy LEBRET

Requirements

The prerequisites are a course in classical control (PID controllers applied to SISO systems) and a course in control of linear MIMO systems defined by a state space representation (controllability, observability, observer state estimated feedback controllers ...).

Objectives

The objective of the course is to give the knowledge and technique to implement Predictive Control and Nonlinear Control.
- Predictive control: the principles of predictive control are more and more implemented in the industry. They will be described and implemented in the context of linear systems through examples developed in tutorials and practical exercises using Matlab.
- Non-linear control: the focus will be on control laws requiring little information on the systems: sliding mode control (standard, higher order, adaptive) and model-free control.

Course contents

Predictive Control
- Introduction, the basis of predictive control
- Prediction techniques for linear systems
- The algorithms of the "Predictive Functional Control" law (PFC) and "Generalized Predictive Control" law (GPC).
- Handling constraints and tunings of GPC.

Nonlinear control
- Sliding mode control: standard, high order, and adaptive
- Model-free control

Course material

- A first course in Predictive Control, J.A. Rossiter. 2018, Édition CRC Press.
- Predictive Functional Control, Principle and Industrial applications, J. Richalet, D. O'Donovan. 2009, Springer
- Commande predictive en Scilab, J. Richalet, G. Lavielle. 2016 Edition D-BookeR.`
- Predictive Control with constraints, J.M. Maciejowski. 2001, Prentice Hall.
- Sliding mode control and observation, Y. Shtessel, C. Edwards, L. Fridman, A. Levant. 2014, Springer.
- Model-free control, M. Fliess, C. Join. International Journal of Control, vol.86, no.12, pp.2228-2252, 2013

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	6 hrs	8 hrs	0 hrs	2 hrs

ENGINEERING - OD ECONTROL

Year 2 / Year 3 - Autumn Semester - Course Unit 74 / 94

Digital design on FPGA [CONUM]

LEAD PROFESSOR(S): Olivier Henri ROUX

Requirements

Objectives

Critical systems are subject to many constraints because they interact closely with dangerous processes. The development of such systems must offer guarantees of proper operation and recovery in case of failure of an internal part or an unanticipated environment. Formal models and methods can be used to guarantee safe operation properties and thus increase the degree of confidence in these systems,
Some embedded systems, for example in avionics, automotive, or wind turbines are particularly critical and have strong real time constraints. Others are energy constrained as they are powered by batteries or super-capacitors that are intermittently recharged by photovoltaic panels.
The aim of this course is to present formal verification models and methods ranging from discrete models (graphs, finite automata) to models that take into account time, parameters and cost variables to model energy consumption.

These same models allow to treat a part of the vast subject of artificial intelligence. Among the many concepts grouped under this generic keyword, we will study more particularly :
- Strategic reasoning, based on graphs and game theory
- graph mining
- non-determinism
- partial observation
- game tree exploration

Course contents

1) Synchronous hardware architectures
2) VHDL and FPGA

Course material

https://en.wikipedia.org/wiki/VHDL

Assessment

Collective assessment: EVC 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	8 hrs	4 hrs	20 hrs	0 hrs	0 hrs

Low tech IoT [LTIOT]

LEAD PROFESSOR(S): Pierre-Emmanuel HLADIK

Requirements

Objectives

This course focuses on connected objects (IoT: Internet of Things) with regard to connected sensors. It provides an understanding of the data exchanges between a microcontroller and a sensor through the asynchronous serial link I2C SPI and CAN buses. The information collected by the sensor is sent on a LPWAN (Low Power Wide Area Network), which allows data to be sent (wirelessly) over a long distance (several km) with a very low energy consumption. In addition to covering these technological principles, we will also discuss aspects related to their use in the context of digital sobriety and sustainability specific to low-tech thinking.

At the end of the course, students will be able to:
- Understand and use the main means of data exchange by bus (asynchronous serial bus, I2C, SPI, CAN) between systems in a heterogeneous embedded architecture,
- Understand and use wireless data exchange with low energy consumption (BLE, LPWAN),
- Know and put into perspective aspects of digital sobriety in the context of embedded systems for the IoT.

Course contents

Introduction (course)
 o Classification of industrial LANs, general principles of communication
Communication by bus (course, TD and TP)
 o Asynchronous serial link
 o I2C bus
 o SPI bus
 o CAN bus
Wireless communication with low energy consumption (course, TD and TP)
 o BLE
 o LPWAM
Introduction to digital sobriety (course, TD)
 o Energy efficiency
 o Characterization and case studies

Course material

- Stéphane Lohier, Dominique Présent, Réseaux et transmissions - 7e édition, Dunod, 2020
- Guy Pujolle, Les reseaux 9e edition, Eyrolles, 2018
- Bharat Chaudhari, Marco Zennaro, LPWAN Technologies for IoT and M2M Applications, Elsevier, 2020

Assessment

Collective assessment:	EVC 1 (coefficient 0.4)
Individual assessment:	EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	8 hrs	8 hrs	14 hrs	0 hrs	2 hrs

ENGINEERING - OD ECONTROL

Year 2 / Year 3 - Autumn Semester - Course Unit 74 / 94

Observation and diagnosis [ODAS]

LEAD PROFESSOR(S): Malek GHANES

Requirements

Objectives

For reasons of technology (materials, feasibility, etc.), reliability (failure or defects of measuring elements) or economics (cost and maintenance of sensors), measurement of all states is not possible in many applications. For example, in the context of electric and hybrid vehicles, there are no torque sensors in electric and hybrid cars. It is therefore necessary, using available measurements, to reconstruct unmeasured state variables. This is the main objective of an observer. In the case of electric and hybrid vehicles, an observer can be designed to reconstruct torque using current measurements for safety reasons. For example, the traction of Renault electric vehicles is stopped if the torque exceeds or fails to reach a threshold of the desired torque, requested by the driver. This observation or estimation problem can be found in control, diagnostics, fault detection and safety contexts, wherever knowledge of state variables may be required. The objectives of the course are therefore focused on the problem of observer/estimator design and diagnosis for linear and non-linear systems, with academic examples and applications in electric propulsion.

Course contents

Course material

[1] M. Taherzadeh, M. A. Hamida, M. Ghanes, and M. Koteich, "A new torque observation technique for a pmsm considering unknown magnetic conditions," IEEE Transactions on Industrial Electronics, vol. 68, no. 3, pp. 1961–1971, 2020.
[2] R. Hermann and A. Krener, "Nonlinear controllability and observability," IEEE Transactions on Automatic Control, vol. 22, no. 5, pp. 728–740, 1977.
[3] T. Kailath, Linear systems, vol. 156. Prentice-Hall Englewood Cliffs, NJ, 1980.
[4] W. M. Wonham, Linear multivariable control geometric approach. Springer-Verlag, 1985.
[5] R. E. Kalman and R. S. Bucy, "New results in linear filtering and prediction theory," Journal of Basic Engineering, vol. 83, no. 1, p. 95, 1961.
[6] D. G. Luenberger, "Observing the state of a linear system," IEEE Transactions on Military Electronics, vol. 8, no. 2, pp. 74–80, 1964.
[7] G. Conte, C. H. Moog, and A. M. Perdon, "Nonlinear control systems : An algebraic setting," 1999.
[8] J.-P. Barbot, D. Boutat, and T. Floquet, "An observation algorithm for nonlinear systems with unknown inputs," Automatica, vol. 45, no. 8, pp. 1970–1974, 2009.
[9] J. Gauthier and G. Bornard, "Observability for any u (t) of a class of nonlinear systems," IEEE Transactions on Automatic Control, vol. 26, no. 4, pp. 922–926, 1981.
[10] H. Hammouri, B. Targui, and F. Armanet, "High gain observer based on a triangular structure," International Journal of Robust and Nonlinear Control : IFAC-Affiliated Journal, vol. 12, no. 6, pp. 497–518, 2002.
[11] K. S. Narendra and A. M. Annaswamy, "Persistent excitation in adaptive systems," International Journal of Control, vol. 45, no. 1, pp. 127–160, 1987.

[12] H. Hammouri and J. de Leon Morales, "Observer synthesis for state-affine systems," in 29th IEEE Conference on Decision and Control, pp. 784–785, IEEE, 1990.
[13] G. Besancon, "Further results on high gain observers for nonlinear systems," in Proceedings of the 38th IEEE Conference on Decision and Control (Cat. No. 99CH36304), vol. 3, pp. 2904–2909, IEEE, 1999.
[14] H. K. Khalil, "High-gain observers in nonlinear feedback control," in New directions in nonlinear observer design, pp. 249–268, Springer, 2007.
[15] J.-j. E. Slotine, J. Hedrick, and E. Misawa, "Nonlinear state estimation using sliding observers," in 1986 25th IEEE Conference on Decision and Control, pp. 332–339, IEEE, 1986.
[16] V. I. Utkin, Sliding modes in control and optimization. Springer Science & Business Media, 2013.
[17] A. Levant, "Robust exact differentiation via sliding mode technique," automatica, vol. 34, no. 3, pp. 379–384, 1998.
[18] W. Perruquetti and T. Floquet, "Homogeneous finite time observer for nonlinear systems with linearizable error dynamics," in 2007 46th ieee conference on decision and control, pp. 390–395, IEEE, 2007.
[19] M. Ghanes, J.-P. Barbot, L. Fridman, A. Levant, and R. Boisliveau, "A new varying-gain-exponent-based differentiator/observer : An efficient balance between linear and sliding-mode algorithms," IEEE Transactions on Automatic Control, vol. 65, no. 12, pp. 5407–5414, 2020.
[20] M. Ghanes, J. A. Moreno, and J.-P. Barbot, "Arbitrary order differentiator with varying homogeneity degree," Automatica, vol. 138, p. 110111, 2022.
[21] "Observability analysis and improved zero-speed position observer design of synchronous motor with experimental results," Asian Journal of Control, vol. 15, no. 4, pp. 957–970, 2013.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	6 hrs	8 hrs	0 hrs	2 hrs

Project 1 [P1ECONTROL]

LEAD PROFESSOR(S): Mohamed Assaad HAMIDA

Requirements

Objectives

Introduce engineering students to the tools of control, energy management and real time systems through projects proposed by the teachers of the option.

Course contents

According to the proposed projects

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	1	0 hrs	0 hrs	0 hrs	32 hrs	0 hrs

Smart energy management [GENER]

LEAD PROFESSOR(S): Mickael HILAIRET

Requirements

Objectives

The objectives of this course are to acquire knowledge and skills on the control of renewable energy (EnR) systems (wind turbine, PV) associated with source/storage systems (fuel cell, electrolyser, batteries, supercapacitors). A GENIUS miro-grid integrating renewable energies and hydrogen-based storage (being set up at the school) will be studied in order to illustrate the interest of supervision (high-level control, optimized and intelligent management of electrical energy) and the design (sizing) of the components.

Course contents

1. PEMFC fuel cell principle
2. Design and development of controllers for power management between a fuel cell and supercapacitors
3. Design of a PV/battery system

Course material

F. K/bidi, C. Damour, D. Grondin, M. Hilairet, M. Benne, "Multistage power and energy management strategy for hybrid microgrid with photovoltaic production and hydrogen storage", Applied Energy, 2022, doi 10.1016/j.apenergy.2022.119549

T. Azib, O. Bethoux, G. Remy, C. Marchand, É. Berthelot. An Innovative Control Strategy of a Single Converter for Hybrid Fuel Cell/Supercapacitor Power Source. IEEE Transactions on Industrial Electronics, 2010, 57 (12), pp.4024-4031. 10.1109/tie.2010.2044123. hal-02054691

M. Hilairet, M Ghanes, O. Béthoux, V Tanasa, J-P Barbot, et al.. A passivity-based controller for coordination of converters in a fuel cell system. Control Engineering Practice, 2013, 21 (8), pp.1097 - 1109. 10.1016/j.conengprac.2013.04.003. hal-00923716v2

Assessment

Collective assessment: EVC 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	6 hrs	16 hrs	0 hrs	0 hrs

Model checking and AI [MCIA]

LEAD PROFESSOR(S): Olivier Henri ROUX

Requirements

Objectives

Critical systems are subject to many constraints because they interact closely with dangerous processes. The development of such systems must offer guarantees of proper operation and recovery in case of failure of an internal part or an unanticipated environment. Formal models and methods can be used to guarantee safe operation properties and thus increase the degree of confidence in these systems,
Some embedded systems, for example in avionics, automotive, or wind turbines are particularly critical and have strong real time constraints. Others are energy constrained as they are powered by batteries or super-capacitors that are intermittently recharged by photovoltaic panels.
The aim of this course is to present formal verification models and methods ranging from discrete models (graphs, finite automata) to models that take into account time, parameters and cost variables to model energy consumption.

These same models allow to treat a part of the vast subject of artificial intelligence. Among the many concepts grouped under this generic keyword, we will study more particularly :
- Strategic reasoning, based on graphs and game theory
- graph mining
- non-determinism
- partial observation
- game tree exploration

Course contents

-Discrete models
-Timed, parameterised and cost models
-Verification, Parameter Synthesis, Strategy Synthesis
-Introduction to deep learning

Course material

Bouyer, P., Fahrenberg, U., Larsen, K. G., Markey, N., Ouaknine, J., & Worrell, J. (2018). Model Checking Real-Time Systems. In Handbook of Model Checking (pp. 1001-1046). Springer Publishing Company. https://doi.org/10.1007/978-3-319-10575-8_29

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	6 hrs	8 hrs	0 hrs	2 hrs

Project 2 [P2ECONTROL]

LEAD PROFESSOR(S): Mohamed Assaad HAMIDA

Requirements

Objectives

Introduce engineering students to the tools of control, energy management and real time systems through projects proposed by the teachers of the option.

Course contents

According to the proposed projects

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	2	0 hrs	0 hrs	0 hrs	48 hrs	0 hrs

Energy Project [PENER]

LEAD PROFESSOR(S): Mickael HILAIRET

Requirements

Objectives

The objectives are the acquisition of skills in the field of electrical system. This ranges from control and observation of electrical systems to the implementation of real-time algorithms on embedded systems.

Course contents

- Establish the specifications according to the needs
- Propose solutions based on the methods seen in class or/and in the literature
- Discuss these solutions in relation to the specifications, possibly questioning these specifications in relation to their economic, technological and societal feasibility
- Design the system
- Make test at least in simulation and in experimentation when possible
- Example of projects: Field Oriented Control without position sensor and observation of the position of a synchronous machine, control of a stepper motor via an FPGA (VHDL, ARM processor), implementation of a PWM to control a full-bridge converter with an STM32 µC, etc.

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	0 hrs	6 hrs	26 hrs	0 hrs	0 hrs

Role of electricity in the energy transition [TENER]

LEAD PROFESSOR(S): Benoit HILLOULIN

Requirements

Objectives

In the first part of this course, the role of electricity in the energy transition will be addressed. The second part is intended for the presentation of the Life Cycle Assessment methodology and the various considerations that must be taken into account when carrying out such a study, in particular the materials useful for the electrification. The most common tools for implementing a Life Cycle Analysis as well as the databases used by specialized software are also presented.
After completing the course, the candidate should acquire the following in-depth knowledge and understanding:

- Understand electrical energy and its role in the energy transition as well as in the global environment (political, climatic, economic, societal)
- Acquire basic knowledge of the principles and methodological framework of the LCA approach, particularly with regard to its implementation, interpretation and analysis of results.

Course contents

- History, general regulatory context, climate issues
- Energy geopolitics and GHG reduction targets
- Renewable energies
- Role of electricity in the energy transition
- Energy efficiency services (decarbonization in industry, regulatory energy audit, ISO 50001 standard, etc.)
- Materials for the electrification (energy and mobility)
- Interest of LCA methods
- Handling of tools dedicated to the realization of LCA
- Application of knowledge through practical work

Course material

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	12 hrs	8 hrs	0 hrs	2 hrs