COURSE DESCRIPTION
CONTROL OF COMPLEX SYSTEMS AND NETWORKS

SSD: AUTOMATICA (ING-INF/04)

DEGREE PROGRAMME: INGEGNERIA DELL'AUTOMAZIONE E ROBOTICA (P38)
ACADEMIC YEAR 2022/2023

COURSE DESCRIPTION

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GENERAL INFORMATION ABOUT THE COURSE

INTEGRATED COURSE: U2326 - ADVANCED CONTROL ENGINEERING
MODULE: U2327 - CONTROL OF COMPLEX SYSTEMS AND NETWORKS
CHANNEL: FG A-Z
YEAR OF THE DEGREE PROGRAMME: II
PERIOD IN WHICH THE COURSE IS DELIVERED: SEMESTER II
CFU: 6

REQUIRED PRELIMINARY COURSES

None

PREREQUISITES

Basic knowledge about closed loop control systems.

LEARNING GOALS

The course aims at providing students with a set of tools for the analysis and control of networks of dynamical systems, with a special emphasis on their optimization and safety, and on their possible use for the design and management in diverse engineering applications.

EXPECTED LEARNING OUTCOMES (DUBLIN DESCRIPTORS)

Knowledge and understanding

The students need to acquire the main methodological tools to model, analyze and control complex systems, with a special emphasis on those that can be described as networks of interconnected dynamical systems. The lectures will guide the students towards a) the comprehension of the links between the topological properties of the graph and the individual dynamics of the nodes, and b) the identification of the causal mechanisms determining the spontaneous emergence of collective behaviors, such as consensus and synchronization. The analytical and numerical tools acquired by the students will be then used to understand the specificities of control design for network systems.

Applying knowledge and understanding

The students need to be capable of applying the acquired methodology to model and analyze real systems that can be described by complex network models, as for instance wireless sensor networks, population dynamics, or formation of autonomous vehicles. Furthermore, the students will need to showcase the ability to apply the control techniques that they learned to design controllers for complex systems in the presence of constraints on the number of input signals and observable nodes.

COURSE CONTENT/SYLLABUS

Part 1 Introduction and background

1 Introduction
1.1 Definition of a complex system
1.2 Complex networks of dynamical systems
1.3 Examples: wireless sensor networks and compartmental models
2 Elements of matrix theory
2.1 Convergent and semi-convergent matrices; eigenvalue classification
2.2 Spectral properties of stochastic matrices
2.3 Geršgorin disks theorem
2.4 Perron-Frobenius theorem
2.5 Examples

Part 2 Graph theory

3 Elements of graph theory
3.1 Directed and undirected graphs
3.2 Main definitions
3.3 Paths, connectivity, and periodicity
3.4 Condensation graphs
3.5 Weighted graphs
3.6 Adjacency matrix
4 Linking graphs and matrices
4.1 Properties of the adjacency matrix
4.2 Some elementary equivalences
4.3 Paths in the graph and powers of the adjacency matrix
4.4 Graphs and irreducible matrices
4.5 Graphs and primitive matrices

Part 3 Analysis and control of networks of linear dynamical systems: the consensus problem

READINGS/BIBLIOGRAPHY

- F. Bullo, Lectures on Network Systems, Edizione 1.3, 2019.
- M. E. J. Newman, A. L. Barabasi, and D. J. Watts, The structure and dynamics of networks, Princeton University Press, 2006.
- Additional references and lecture notes available in the tab file of the Teams class of the module

Further reading and material:
- Siljak, D. D. Decentralized control of complex systems. Courier Corporation, 2011.
- A. Barrat, M. Barthelemy, A. Vespignani, Dynamical Processes on Complex Networks, Cambridge University Press, 2008.
- Uri Alon lab dataset. Available at http://www.weizmann.ac.il
- Pajek's dataset Available at: http://vlado.fmf.uni-lj.si/pub/networks/data

TEACHING METHODS OF THE COURSE (OR MODULE)

The teaching activities will be organized as follows: a) lectures for about 70% of the total hours, b) practical exercise in the classroom based on software tools (Matlab-simulink) for about 30% of the total hours.

EXAMINATION/EVALUATION CRITERIA

a) Exam type

- [ ] Written
- [x] Oral
- [ ] Project discussion
- [ ] Other

In case of a written exam, questions refer to

- [ ] Multiple choice answers
- [ ] Open answers
- [ ] Numerical exercises

b) Evaluation pattern

The oral exam is focused on the discussion of a homework assigned to the student by the instructor. The oral examination will also aim at assessing the knowledge of all the concepts and contents given during the lectures.