Course guides
205092 - 205092 - Dynamical Systems in Engineering

Last modified: 18/05/2020

Unit in charge: Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 749 - MAT - Department of Mathematics.

Degree: MASTER'S DEGREE IN INDUSTRIAL ENGINEERING (Syllabus 2013). (Optional subject).
MASTER'S DEGREE IN AERONAUTICAL ENGINEERING (Syllabus 2014). (Optional subject).
MASTER'S DEGREE IN SPACE AND AERONAUTICAL ENGINEERING (Syllabus 2016). (Optional subject).

Academic year: 2020 **ECTS Credits:** 3.0 **Languages:** English

LECTURER

Coordinating lecturer: Mañosa Fernandez, Victor

Others:

PRIOR SKILLS

Students must have consolidated math skills at a bachelor's degree in engineering level.

REQUIREMENTS

Students must have knowledge of Calculus in several variables, linear algebra and differential equations.

TEACHING METHODOLOGY

- Face-to-face lecture sessions.

- Face-to-face practical work sessions.

- Autonomous study, realization of exercises and development of certain theoretical contents.

- Presentation of the exercises or the theoretical contents in class.

In the face-to-face lecture sessions, the lecturer will introduce the basic theory, concepts, methods and results for the subject and use examples to facilitate students' understanding. Students will be expected to study in their own time so that they are familiar with concepts and are able to solve the exercises set, either manually or with the help of a computer. The use of IT support tools will be encouraged: students will learn how to use a mathematical software package as a tool for performing numerical, symbolic and graphic calculations.

LEARNING OBJECTIVES OF THE SUBJECT

Dynamical systems theory is a fascinating and wide area of science that deals with the time evolution of deterministic models. Its scope go beyond mathematics and its applications involve physics (movement of celestial bodies or satellites, heat evolution, mechanics…), biology (evolution of population and epidemics, neuroscience, cell growth...), chemistry (chemical reactions), new technologies (complex networks), economy…

The course is addressed to newcomers to dynamical systems. The fundamental concepts and tools to understand nonlinear dynamics will be given.
The main objective is to provide tools to analyze the following two objects:

• The phase portrait, which serves to determine the time evolution (past and future) of the system states based on their present values;

• The bifurcation diagram in the parameter space, which is meant to describe how a specific feature of the system varies as we move the parameters, and when it happens a bifurcation phenomenon: a change in the qualitative behavior of the system's dynamics.
We will work both from an analytical level and from a geometric intuitive one and a special emphasis will be placed on physical and biological models: mechanical vibrations, lasers, circuits, population dynamics, epidemics…

STUDY LOAD

Type	Hours	Percentage
Self study	48,0	64.00
Hours small group	12,0	16.00
Hours large group	15,0	20.00

Total learning time: 75 h

CONTENTS

1. Introduction to dynamical systems and nonlinear models

Description:
a. What are dynamical systems? Examples of physical and biological nonlinear models.

b. Maps and flows: the phase portrait, the concept of bifurcation.

c. Special type of solutions: equilibrium points (steady states), periodic orbits

Full-or-part-time: 8h
Theory classes: 2h
Laboratory classes: 2h
Self study : 4h

2. Dynamical Systems in one dimension

Description:
a. Qualitative analysis continuous systems.

b. Discrete systems: the logistic map, chaos in the Devaney's sense.

c. Local bifurcations of 1-dimensional systems.

d. Applications to nonlinear models in science and engineering.

Full-or-part-time: 8h
Theory classes: 2h
Laboratory classes: 2h
Self study : 4h

3. Linear systems and linearization of nonlinear systems

Description:
a. Qualitative analysis of 2-dimensional linear systems. Stability.

b. Higher order linear systems.

c. Local linearization: Stable, unstable and central manifolds. Hartman-Grobman theorem.

d. Applications to nonlinear models in science and engineering.

Full-or-part-time: 24h
Theory classes: 4h
Laboratory classes: 4h
Self study : 16h

4. Stability of nonlinear systems

Description:
a. Stability and asymptotic stability.

b. Lyapunov functions.

Full-or-part-time: 4h
Theory classes: 1h
Laboratory classes: 1h
Self study : 2h

5. Dynamical Systems in two dimensions

Description:
a. Periodic orbits.

b. Limiting behaviors: the Poincaré-Bendixon Theorem.

c. Bifurcations in 2-dimensional systems.

d. Applications to nonlinear oscillations. Biological rhythms.

Full-or-part-time: 18h
Theory classes: 3h
Laboratory classes: 3h
Self study : 12h

6. Dynamical Systems in higher dimensions

Description:
a. Deterministic Chaos: the Lorenz Equations.

b. Chaos in nonlinear models in science and engineering.

c. Dynamical systems in celestial mechanics: chaos in the solar system.

d. Complex networks. Synchronization.

Related activities:
Module 6 (Dynamic systems in higher dimensions) will consist of a brief bibliographic work on one of the topics of the module, which will be one of the deliverables of the course.

Full-or-part-time: 13h
Theory classes: 3h
Self study : 10h

GRADING SYSTEM

Delivery of tasks corresponding to each module: 100%.

The final grade will be the average of the grades of the tasks with the following indicative weights:

Modules 1-2: 25%

Module 3: 25%

Modules 4 and 5: 25%

Module 6: 25%

Module 6 is presented as a bibliographic work on one of the topics of the module or some other topic previously agreed.

Deliverables will consist of various types of tasks such as solving exercises, performing simulations, the analysis of a model or, occasionally, the theoretical development of a topic.

Mechanisms for improvement of the grade of each task will be established.

EXAMINATION RULES.

A deadline will be established for the delivery of the tasks. All assignments delivered up to 48h after the deadline will have a 50% penalty. Deliveries will not be accepted after this second deadline.

BIBLIOGRAPHY

Basic:
- Strogatz, Steven H. Nonlinear dynamics and chaos: with applications to physics, biology, chemistry and engineering . Cambridge : Perseus, 1994. ISBN 0-7382-0453-6.
- Arrowsmith, D. K; Place, C. M. Dynamical systems: differential equations, maps, and chaotic behaviour . 1st ed. London; New York : Chapman & Hall, 1992. ISBN 0-412-39080-9.

Complementary:
- Solé Vicente, Ricard; Manrubia, Susanna C. Orden y caos en sistemas complejos . Barcelona : Edicions UPC, 2001. ISBN 8483014912.
- Borrelli, Robert L; Coleman, Courtney S. Ecuaciones diferenciales: una perspectiva de modelación . México : Oxford University Press, 2002. ISBN 970-613-611-8.
- Kuznetsov, Yuri A. Elements of applied bifurcation theory . 3rd ed. New York : Springer, 2004. ISBN 978-0-387-21906-6.
- Hale, Jack K; Koçak, Hüseyin. Dynamics and bifurcations . New York : Springer-Verlag, 1991. ISBN 0-387-97141-6.
- Braun, Martin. Differential equations and their applications: an introduction to applied mathematics . 4th ed. New York, NY [etc.] : Springer-Verlag, cop. 1993. ISBN 978-0-387-97894-9.

RESOURCES

Other resources:
The use of the Maple and/or Matlab program (or other equivalents) to perform the calculations will be encouraged. Students will occasionally be recommended to server a phase portrait simulation program such as pplane which can be downloaded at:

https://www.cs.unm.edu/~joel/dfield/