220125 - Nonlinear Systems, Chaos and Control in Engineering

Coordinating unit: 205 - ESEIAAT - Terrassa School of Industrial, Aerospace and Audiovisual Engineering
Teaching unit: 748 - FIS - Department of Physics
Academic year: 2017
Degree: BACHELOR'S DEGREE IN AEROSPACE TECHNOLOGY ENGINEERING (Syllabus 2010). (Teaching unit Optional)
BACHELOR'S DEGREE IN AEROSPACE VEHICLE ENGINEERING (Syllabus 2010). (Teaching unit Optional)
BACHELOR'S DEGREE IN INDUSTRIAL TECHNOLOGY ENGINEERING (Syllabus 2010). (Teaching unit Optional)
ECTS credits: 3
Teaching languages: English

Teaching staff
Coordinator: Cristina Masoller
Others: A.J. Pons

Teaching methodology
Theory classes: The course is divided into three parts, that will introduce the theory of nonlinear systems in a systematic way, starting with a general overview, then presenting analytical methods for one-dimensional systems (fixed points and their bifurcations), followed by two-dimensional systems (limit cycles and their bifurcations) and culminating with three dimensional systems, chaos, fractals and strange attractors. Mathematical concepts will be gradually introduced. Emphasis will be given to specific examples (e.g. mechanical vibrations, lasers, chaotic circuits) that will facilitate the understanding of the theory of nonlinear systems and emphasize its relevance for technological applications.
Practical classes: experimental demonstrations as well as hands-on sessions to solve problems via computer simulations will be offered.
Self-study for doing exercises and activities: The students will work in small groups (2-3 students) the problems proposed by the Lecturers.
The lecturers will provide the required materials and will monitor the activities via ATENEA.

Learning objectives of the subject
Acquire a general understanding of the behavior of nonlinear systems and chaotic systems, with emphasis on control techniques and their practical applications to Engineering problems.

Study load

<table>
<thead>
<tr>
<th>Total learning time: 75h</th>
<th>Hours large group:</th>
<th>30h</th>
<th>40.00%</th>
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<tbody>
<tr>
<td></td>
<td>Self study:</td>
<td>45h</td>
<td>60.00%</td>
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Content

**Module 1: Introduction and analysis of one-dimensional nonlinear systems**

<table>
<thead>
<tr>
<th>Description:</th>
<th>Learning time: 25h</th>
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<td>There will be a broad overview of nonlinear and chaotic systems and several examples will be discussed. The relevance of nonlinear effects and dynamical effects will be stressed in relation with linear approximations.</td>
<td>Theory classes: 10h</td>
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<td>Self study : 15h</td>
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**Related activities:**
The students will be offered hands-on sessions on computer simulations on integrating the model equations and computing bifurcation diagrams.

**Specific objectives:**
1. One dimensional systems will be analyzed, employing linear stability analysis and going beyond to the concept of bifurcations.
2. Control of nonlinear systems through delay feedback will be studied.
3. Practical examples to be discussed include a laser model, a neuron model, an ecological system and an over-damped pendulum.

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**Module 2: Two-dimensional Flows**

<table>
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<tr>
<th>Learning time: 25h</th>
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<tbody>
<tr>
<td>Theory classes: 10h</td>
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<tr>
<td>Self study : 15h</td>
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**Description:**
1. Two-dimensional linear systems will be analyzed in detail. As a working example, the harmonic oscillator will be considered to demonstrate different concepts as vector fields on the phase space or phase portraits.
2. The dynamics of the phase space will be characterized for two-dimensional nonlinear systems. Fixed points and linearization will be presented. Dynamics of different systems coming from Physics and Technology will be workout as examples of the techniques presented in this block.
3. Limit cycles of two-dimensional flows will be studied paying special attention to their Bifurcation analysis. Hysteresis, coupled oscillators and maps will be introduced.

**Related activities:**
Hands-on group sessions on numerical techniques and simulations for two-dimensional dynamical systems. Computer code for these sessions will be programmed in Matlab.
Module 3: Chaotic dynamics

Description:
1. In this module we will discuss examples of chaotic nonlinear systems in three dimensions. Examples will include the Lorenz system and its technological applications, and chaotic electronic circuits.
2. The last part of the course will be devoted to characterization of chaos. We will discuss the exponential separation of trajectories and the concept of Lyapunov exponents. Finally, we will discuss chaotic attractors and introduce fractals and the idea of fractal dimension.

Related activities:
Hands-on session on numerical simulation of chaotic systems. Numerical estimation of Lyapunov exponents and fractal dimension with Matlab.

Learning time: 25h
- Theory classes: 10h
- Self study: 15h

Qualification system

The final grade will be the average of the three grades obtained in the three reports:

\[ NF = 0.333 \times N1 + 0.333 \times N2 + 0.333 \times N3 \]

Where NF is the final grade and N1, N2, N3 are the grades obtained in three reports.

Bibliography

Basic:

Complementary:

Others resources:
- TED Lectures
  - http://www.ted.com/talks/steven_strogatz_on_sync