MAE 279: Dynamics and Control of Biological Oscillations

Lectures: TR 14:00-15:50 Boelter 5280

Instructor

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Class Homepage:
https://ccle.ucla.edu/course/view/18S-MECHAE279-1

Course Description:

Oscillations are often observed in nature at various levels, and form a basis for sustained operation of various functionalities. This course focuses on analysis and design of the dynamical mechanisms underlying biological control systems that generate coordinated oscillations. Topics include neuronal information processing through action potentials (spike train), central pattern generator, coupled nonlinear oscillators, optimal gaits (periodic motion) for animal locomotion, and entrainment to natural oscillations via feedback control.

Prerequisites:

MA 107 Introduction to Modeling and Analysis of Dynamic Systems
MA 270A Linear Dynamic Systems
The students are expected to already know basics of linear dynamical systems, including the frequency response, transfer functions, stability, and state space. The course will require mathematical backgrounds in ordinary differential equations, Laplace and Fourier transforms, and linear algebra. These materials will be reviewed in class if necessary.

Textbook:

Lecture notes prepared by the instructor and technical papers in the literature will be used in place of a textbook.

Homework:

Approximately one assignment every other week
Due in a week from the date of assignment
Late homework will NOT be accepted.

Exams: (Probably in a “take-home” format)

Midterm Exam: Late April – Early May
Final Exam: Early June
Grades:

Homework 30%
Midterm Exam 30%
Final Exam 40%

MAE 279 Course Topics

1. Overview
   (a) Oscillations in biology
   (b) Nonlinear oscillator theories
   (c) Animal locomotion

2. Basics of Oscillations
   (a) Equilibrium and Hartman-Grobman theorem
   (b) Periodic orbit and Poincare-Bendixson theorem
   (c) Planar oscillators and phase plane analysis
   (d) Bifurcations

3. Central pattern generators (CPGs)
   (a) Multivariable harmonic balance
   (b) Analysis of oscillation profile
   (c) Design of neuronal network

4. Animal locomotion and optimal gaits
   (a) General rectifier models
   (b) Undulatory swimming
   (c) Thrust generation mechanisms
   (d) Optimal periodic movements for locomotion

5. Feedback control for coordinated oscillations
   (a) CPG control for arbitrary oscillations of state space systems
   (b) Pattern formation via eigenstructure assignment
   (c) Resonance entrainment by reciprocal inhibition oscillator

6. Further topics with rigorous theoretical analyses
   (a) Linear periodic systems and Floquet theory
   (b) Orbital stability
   (c) Malkin theorem
   (d) Energy regulation of a pendulum
   (e) Coupled harmonic oscillators
   (f) Adaptive Andronov-Hopf oscillator