Spring 2007

ME 597A Thermodynamic Formalism of Dynamical Systems

Instructor: Professor Asok Ray

Schedule No. 837058 Mondays and Wednesdays 2:30 PM to 3:45 PM 212 Hammond

Web Address: http://www.mne.psu.edu/ray/graduate_courses.html

I. Instructional Goals

This 3-credit graduate course is proposed for:

- Development of the theory of nonlinear dynamics from a thermodynamic perspective with applications to diverse fields of science and engineering
- Cross-disciplinary course work for research in dynamical systems modelling & simulation, and decision & control
- Computational and experimental laboratory work on application examples in engineering, applied mathematics, and applied physics.

II. Course Description

A. Introduction to Dynamical Systems

- Dynamical Systems - physical and statistical perspectives
- Complexity of nonlinear dynamical systems - chaos and strange attractors
- Complexity of thermodynamic systems - phase transitions
- Core concepts of dynamical systems and their relationships to:
  - ***Nonlinear Mechanics***
  - ***Fractal Mathematics***
  - ***Statistical Mechanics***
  - ***Information Theory***

B. Essentials of Nonlinear System Dynamics

- Nonlinear maps, trajectories, and stable and unstable maifolds
- Fractals and fractional operators
- Bifurcation, chaos, and strange attractors
- Chaos in Hamiltonian systems

C. Essentials of Thermodynamics and Information Theory

- Generalized canonical distributions - maximum entropy principle, and microcanonical, pressure, and grand canonical ensembles
- Legendre transformation and Gibbs-Duehem relation
- Fractal and multi-fractal representation of thermodynamic relations
- Susceptibilities and fluctuations
- Shannon information and Rényi information
- Kolmogorov-Sinai information and dynamic Rényi information

D. Introduction to Spin Systems

- Various types of spin models – magnetic dipole and lattice gas
- Equivalence between one-dimensional spin system (e.g., Ising, Potts) model and symbolic stochastic processes
- Introduction to two-dimensional spin system (Onsager) model of the Lattice Gas
- The transfer matrix method

E. Dynamical Analysis of Chaotic Systems

- Statistics of dynamical symbol sequences
- Topological pressure and length scale interpretation
- Expansion rate and information loss
- Transfer operator methods - Perron-Frobenius operator
- Repellers and escape
- Phase transitions of spin systems

F. Laboratory Exercises

- ***Computational Laboratory***: Symbolic time series analysis of data from various applications:
  - ***Structural vibration and Fatigue fracture***
  - ***Fluid motion and Turbulence***
  - ***Electronic oscillations***
  - ***Thermo-acoustics of combustion processes***
- ***Experimental Laboratory***: (Individual or group) Course projects for validation of theoretical results on one or more of the following experimental apparatuses:
  - ***Multi degree-of-freedom nonlinear mechanical systems***
  - ***Fatigue fracture in ductile alloys with optical, ultrasonic, and mechanical sensing***
  - ***Multi degree of freedom nonlinear electronic circuits***
  - ***Electrical motors (wound-rotor and squirrel-cage type)***
  - ***Networked robotic systems***

G. Application Areas

- Anomaly detection in large scale dynamical systems (e.g., Transportation, Energy generation, Communication networks, and Battlefield Command and Control)
- Coordinated control of multiple autonomous and semi-autonomous (robotic) systems

I. Prerequisites:

Graduate standing in Science or Engineering

References

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