University of Waterloo
ECE 688: Nonlinear Systems
Winter 2022 (tentative)

Lectures: [redacted]

Instructor: Prof. Christopher Nielsen.
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Course description: Virtually all systems are nonlinear in nature. Sometimes it is possible to describe the operation of a system by a linear model. This is the case, for example, if the mode of operation of the system does not deviate too much from the "nominal" set of operating conditions. But in analyzing the behaviour of any system, one often encounters situations where the linearized model is inadequate or inaccurate. That is the time that the material covered in this course may prove useful.

In this course we cover classical and modern approaches to the analysis of finite-dimensional, deterministic, nonlinear systems modeled by ordinary differential equations with an emphasis on stability, robustness and the effect of interconnecting dynamical system and provide an introduction to nonlinear stabilization. The material in this course may appeal to engineers interested in a rigorous treatment of nonlinear systems and finds applications in every branch of engineering.

Recommended background: Undergraduate calculus and linear algebra; some exposure to state-space models.

Text: Course notes are available on the course website. The optional suggested textbook is

Nonlinear Systems, 3rd edition, H.K. Khalil.

Additional references

- Nonlinear Systems Analysis, 2nd edition. M. Vidyasagar (2002).
- Nonlinear Dynamical Systems and Control: A Lyapunov-Based Approach. W. Haddad and V. Chellaboina (2008).
- Differential Equations, Dynamical Systems, and Linear Algebra. M. Hirsch and S. Smale (1974).

Evaluation:

50% Final exam: open book.

35% Assignments: Four (4) assignments spread over the term.

5% Student delivered tutorials (if sufficient enrolment). Schedule to be determined.

10% Course project.

Tentative Topics List:

1. **Introduction to nonlinear models and phenomena**
   Examples.

2. **Mathematical preliminaries**
   Norms, basic topology, continuity and differentiation.

3. **Dynamical systems and differential equations**
   Dynamical systems, vector fields and local flows, existence and uniqueness.

4. **Key concepts in dynamics**
   Equilibria and closed orbits, invariant sets, limit sets, linearization of nonlinear systems.

5. **Stability theory**
   Notions of stability, Lyapunov's direct method, the invariance principle, exponential stability and linearization, converse theorems.

6. **Introduction to nonlinear stabilization**
   Control Lyapunov functions, Artstein-Sontag theorem, Brockett's necessary conditions for continuous stabilizability.

7. **Passive systems**
   Definitions, passivity-based stabilization, application to Hamiltonian control systems, damping control.

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