

ECE 792 Safety-Critical Control of Robotic Systems

Fall 2026 Unofficial Syllabus

Course Information

Course Title: ECE 792 Safety-Critical Control of Robotic Systems

Course Instructor: Dr. Max Cohen — mhcohen2@ncsu.edu — Engineering Building II 2004B

Meeting Time and Location: Mondays and Wednesday from 4:30pm – 5:45pm in EB2 1220

Course Description: Tools from nonlinear dynamical systems and control provide an elegant framework for formally characterizing the properties of complex engineering systems. Intended for advanced graduate students, this course presents a modern take on the foundations of nonlinear control, focusing on concepts that have demonstrated practical success in controlling complex robotic systems. Topics addressed include foundations of nonlinear dynamics, reachability analysis, control Lyapunov functions, control barrier functions, safety filters, and optimization-based controllers. Emphasis will be placed on both the theoretical foundations of these techniques and their practical applications to robotic and autonomous systems, such as autonomous vehicles, aerial robots, robotic manipulators, and legged robots. While the topics covered are motivated by their application in robotics, the core concepts are broadly applicable to other engineering domains where nonlinear dynamics and feedback control are prevalent.

Prerequisites

The most relevant prerequisite for this course is ECE 516 System Control Engineering or a similar graduate-level controls course, e.g., taken in a different department or at another institution. In principle, the material of this course can be understood without first taking ECE 516 if one has a certain degree of “mathematical maturity.” Students will be expected to have a strong background in linear algebra, calculus, and differential equations, and should probably have had some graduate-level exposure to control systems. Students should also feel comfortable programming in a language of their choice, such as MATLAB, Python, Julia, or C/C++.

Learning Outcomes

Upon completion of this course, students will be able to:

- **Analyze** the behavior of nonlinear systems and characterize system-theoretic properties such as stability or set invariance.
- **Design** nonlinear control algorithms that enforce properties such as stability or set invariance upon a given dynamical system.
- **Implement** advanced control techniques, such as optimization-based feedback controllers, in code.
- **Evaluate** the trade-offs between different algorithmic approaches for solving nonlinear control problems and **justify** the selection of a proposed approach for a given application.

Course Materials

Required Textbook: There is no required textbook for this class. Lecture notes will be provided throughout the semester that cover course content and provide references for further reading. There are various supplemental texts that may be helpful to consult from time-to-time, outlined below.

Optional Materials: This course blends traditional elements from nonlinear control with more recent research developments in robotics and control systems. While there is no required textbook, students may find it useful to consult foundational texts from nonlinear systems and control for a more in-depth account of certain topics. A few books that may help supplement the material in this course are:

- Hassan K. Khalil, “Nonlinear Systems,” Prentice Hall, Third Edition, 2002;
- Jean-Jacques E. Slotine and Weiping Li, “Applied Nonlinear Control,” Prentice Hall, 1991 ([Supporting video lectures](#));
- Alberto Isidori, “Nonlinear Control Systems,” Springer, 1995.

This course will cover a lot of mathematical concepts at a rapid pace. A few books that may help supplement the mathematical prerequisites for this course are:

- Barbara B. Hubbard and John H. Hubbard, “Vector Calculus, Linear Algebra, and Differential Forms: A Unified Approach,” *Matrix Editions*, 2015;
- Stephen Abbott, “Understanding Analysis,” *Springer*, 2015.

Course Assessments, Grading, and Feedback

Homework Assignments (30%): Assessments that go along with weekly lecture content. Grading criteria are included within each assignment. Consists of both conceptual questions and short programming tasks. Allowed to work in small groups (2-3 students), but must write up your own answers and code.

Midterm Exam (30%): There will be a midterm exam approximately halfway through the course. Content will be similar to the conceptual questions asked on homework assignments. Midterm will take place in class.

Project Report (30%): There will be a course project that requires you to apply the tools discussed in the course (or closely related tools) to an advanced problem of your choosing. Projects can be done in small groups and more details will be provided in the course.

Project Presentation (10%): In place of a final exam, we will hold project presentations that require you to present the motivation, methods, and results behind your project to the instructor and other course participants.

List of Topics and Tentative Schedule

This course will cover the following topics in roughly the order outlined below. One lecture will be taken up by the midterm exam. This exact schedule is subject to change at the instructor’s discretion.

Background and Motivation

Lecture 1: Course Introduction

Lecture 2: A Gentle Introduction to Nonlinear Systems

Lecture 3: A Not So Gentle Mathematical Review

Foundations of Nonlinear Dynamical Systems

Lecture 4: Existence and Uniqueness of Solutions

Lecture 5: Comparison Principles

Lecture 6: Set Invariance

Lecture 7: Nagumo's Theorem

Lecture 8: Notions of Stability

Lecture 9: Lyapunov's Direct Method

Lecture 10: Exponential Stability and Linearization

Lecture 11: Robust Notions of Stability

Lecture 12: Advanced Stability Theorems

Nonlinear Control Design

Lecture 13: Control Lyapunov Functions

Lecture 14: Backstepping

Lecture 15: Robust Nonlinear Control

Lecture 16: Adaptive Nonlinear Control

Lecture 17: Actuation Decompositions and Normal Forms

Lecture 18: Nonlinear Zero Dynamics

Lecture 19: Nonlinear Optimal Stabilization

Safety-Critical Control

Lecture 20: Safety-Critical Control and Control Barrier Functions

Lecture 21: Safety Filters and Optimization-based Control

Lecture 22: Constructing Control Barrier Functions

Lecture 23: Robust Safety-Critical Control

Lecture 24: Adaptive Safety-Critical Control

Lecture 25: Multi-Layered Safety-Critical Control

Lecture 26: Viability Kernels and Reachability Analysis

Lecture 27: Implicit Control Barrier Functions