AE 598: Formal Methods in Aerospace Robotics

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Overview

This course presents standard and advanced formal methods for providing performance guarantees in motion planning and control (guidance and control) of nonlinear dynamical systems under uncertainty, with a special focus on aerospace and robotic systems. It covers both textbook materials and current research trends.

Soft Prerequisites

Statistics (STAT 361, STAT 400, or MATH 461), robotics (AE 482, ECE 470, or ME 445), and feedback control (AE 454 or ECE 486), or permission of instructor. It is desirable also to have some basics of optimal control (AE 504 or ECE 515).

Web Page

https://canvas.illinois.edu/courses/52499

Lecture Time and Location

1:00 PM - 2:20 PM on Mondays and Wednesdays, 410B1 Engineering Hall (TBD)

Instructor's Office Hours

2:30 PM - 3:00 PM on Mondays and **3:45 PM - 4:15 PM** on Wednesdays (319L Talbot Laboratory & Zoom), or by appointment

Objectives

Upon completion of this course, you will learn:

- Standard approaches to deriving formal mathematical guarantees in motion planning and control of nonlinear systems
- State-of-the-art and state-of-the-practice formal methods in aerospace robotics
- Research-oriented skills in formulating and solving meaningful problems in relevant fields

Topics

To various levels of detail, this course would cover:

- Unique challenges in aerospace robotics
- Robust and adaptive robot control
- Motion planning in aerospace robotics
- Safety in motion planning and control
- Risk-awareness in motion planning and control
- Robustness and uncertainty quantification
- Safe reinforcement learning
- Learning-based/data-driven planning and control
- Applications and research trends in aerospace robotics

Course Format

This course will be taught primarily using slides to be posted on Canvas.

Textbooks

There are no required textbooks, but some of the course topics are based on the following:

- Applied Nonlinear Control by Jean-Jacques E. Slotine and Weiping Li (recommended)
- Optimal Control Theory by Donald E Kirk (recommended)
- Probabilistic Robotics by Dieter Fox, Sebastian Thrun, and Wolfram Burgard (recommended)
- Analytical Mechanics of Space Systems by Hanspeter Schaub and John Junkins (optional)
- Nonlinear Systems by Hassan K. Khalil (optional)
- Neuro-Dynamic Programming by Dimitri Bertsekas (optional)
- Reinforcement Learning: An Introduction by Andrew Barto and Richard S. Sutton (optional)

Course Project and Assignments

There is no midterm or final exam; instead, you will work on a course project. Up to 5 assignments will be given, each designed to support and enhance the progress of the project. This is optional, but it would be beneficial for you to identify target conferences/journals and present the final results in their preferred format.

1. The project instructions and assignments will be posted on Canvas
2. Potential topics for the project will be provided, but you are welcome to work on your own ideas as long as they align with the scope of this course
3. You can work on any of the following:

- a novel research problem
- an ongoing research project in your group
- reproducing existing research papers with some incremental novelty

4. You are expected to submit a short project proposal somewhere in the middle of the semester
5. You may work individually or as a team, but the complexity of the project and corresponding results should be proportional to the size of the team
6. Each student must have a clearly indicated contribution to the project
7. All students must adhere to the honor code (see below) throughout the course project and all the assignments

Grading

The grades will be weighed as follows

- Assignments: 60%
- Course project: 40%

Anticipated Course Schedule

This is a newly established course, so the schedule may vary significantly depending on the students' levels of understanding.

Week	**Topics**	**Start Date**	**End Date**
1	Introduction to aerospace robotics	Jan. 21	Jan. 24
2	Brief review of robotics	Jan. 27	Jan. 31
3	Brief review of optimal control and robust control	Feb. 3	Feb. 7
4	Robust and adaptive robot trajectory control	Feb. 10	Feb. 14
5	Robust motion planning and Lyapunov functions	Feb. 17	Feb. 21
6	Robust motion planning and contraction metrics	Feb. 24	Feb. 28
7	(**Online**?) Safe motion planning and barrier functions	Mar. 3	Mar. 7
8	Stochastic motion planning and risk metrics	Mar. 10	Mar. 14

9	Distributed multi-agent robot control	Mar. 17	Mar. 21
10	Project proposal development and submission	Mar. 24	Mar. 28
11	Learning-based/data-driven motion planning and control	Mar. 31	Apr. 4
12	Model-free adaptive control and reinforcement learning	Apr. 7	Apr. 11
13	Structural formal guarantees in model-free control	Apr. 14	Apr. 18
14	Augmented formal guarantees in model-free control	Apr. 21	Apr. 25
15	Research trends in aerospace robotics and final presentation	Apr. 28	May 2
16	Final presentation, continued	May 5	May 7

Honor Code

The details can be found here (https://studentcode.illinois.edu/article1/part4/1-401/). There is also a good summary of the honor code here (https://siebelschool.illinois.edu/academics/honor-code) from the School of Computing and Data Science