AE 598: Estimation of Dynamical Systems

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Fall 2025

Overview

This course offers a rigorous mathematical foundation for the estimation of general linear and nonlinear systems, with a few selected examples from aerospace applications. Particular emphasis is placed on deriving formal performance guarantees for various estimation methods to ensure their trustworthy deployment in real-world scenarios. It further introduces a modern, statistical perspective on nonlinear estimation and prediction, now playing an increasingly important role in the formal verification of AI and machine learning approaches.

Prerequisites

STAT 361, STAT 400, MATH 461, AE 353 (or something equivalent), and familiarity with a programming language (Python, Matlab, etc.)

Web Page

https://canvas.illinois.edu/courses/60755/

Lecture Time and Location

12:30 PM - 1:50 PM on Tuesdays and Thursdays, 403B2 Engineering Hall

Instructor's Office Hours

TBD: 2:00 PM - 2:30 PM on Tuesdays and 2:00 PM - 2:30 PM on Thursdays (319L Talbot Laboratory & Zoom), or by appointment

Objectives

Upon completion of this course, a student will learn to:

- Design appropriate estimators for given linear/nonlinear dynamical/static systems
- Derive formal mathematical guarantees for these estimators given real-world data
- Implement them in aerospace systems

Topics

To various levels of detail, this course would cover:

- Brief review of probability and statistics
- Least-squares & minimum variance estimation
- Maximum likelihood estimation
- Gradient descent and learning
- Lyapunov theory in estimation
- Bayesian filtering
- Luenberger observer & optimal estimation
- Contraction theory & nonlinear estimation
- Conformal inference for data-driven systems
- Introduction to formal verification in AI and machine learning
- Estimation in aerospace and robotic systems

Course Format

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

Recommended Textbooks

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

- Introduction to Random Signals and Applied Kalman Filtering
- Optimal Estimation of Dynamical Systems
- Statistical Orbit Determination

Assignments and Project

There will be up to 5 assignments depending on the progress. Midterm and final will be take-home and closed book. They will be posted on and submitted through Canvas. Collaboration is strongly encouraged for assignments but is not allowed for exams. All students must adhere to the honor code (see below) when taking exams. Violations of the honor could result in failure of the course.

Grading

The grades will be weighed as follows

- Assignments: 60%
- Midterm: 20%
- Final: 20%

Anticipated Course Schedule

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

Week	**Topics**	**Start Date**	**End Date**
Week 1	Introduction and reviews of probability and statistics	Aug. 25	Aug. 29
Week 2	Minimum variance and maximum likelihood estimation	Sep. 1	Sep. 5
Week 3	Nonlinear least squares	Sep. 8	Sep. 12
Week 4	Gradient descent and machine learning	Sep. 15	Sep. 19
Week 5	Dynamical systems and Lyapunov theory	Sep. 22	Sep. 26
Week 6	Bayesian estimation and Kalman filter	Sep. 29	Oct. 3
Week 7	Optimal estimation and Kalman filter	Oct. 6	Oct. 10
Week 8	Riccati equation and Kalman filter	Oct. 13	Oct. 17
Week 9	Nonlinear estimation tools	Oct. 20	Oct. 24
Week 10	Midterm (TBD) & Lyapunov theory	Oct. 27	Oct. 31
Week 11	Contraction theory for nonlinear estimation	Nov. 3	Nov. 7
Week 12	Conformal inference for data-driven systems	Nov. 10	Nov. 14
Week 13	Introduction to formal verification in AI and ML	Nov. 17	Nov. 21
Week 14	Parameter estimation and adaptation	Nov. 24	Nov. 28
Week 15	Estimation in aerospace and robotic systems	Dec. 1	Dec. 5
Week 16	Final (TBD)	Dec. 8	Dec. 10

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