EE-371 - Estimation Theory

University of Vermont
Electrical and Biomedical Engineering Department

Spring Semester 2020

Instructor

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Instructor's Office Hours

Time: Wednesdays 2:00-4:00pm (or by appointment)

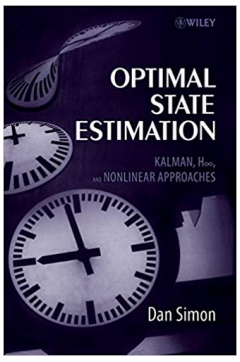
Lectures Time and Location

Time: Tuesdays and Thursdays - 10:05 - 11:20am
Location: Votey Hall 223

Prerequisites

EE 151 or instructor permission.

Textbook



Optimal State Estimation: Kalman, H_∞, and Nonlinear Approaches, Dan Simon, Wiley, 2006.

It is not absolutely necessary to buy this textbook, because equivalent material is also available by other authors (see references below).

Other References for probability, estimation and Kalman filtering

- *Advanced Kalman Filtering, Least Squares and Modeling*, B. Gibbs, Wiley, 2011.
- *Applied Optimal Estimation*, A. Gelb, The Analytic Sciences Corporation, 1974.
- *Fundamentals of statistical signal processing: Estimation theory*, Steven Kay, Prentice-Hall, Inc., 1993.

- *Introduction to random signal analysis and Kalman filtering*, R. Brown, Wiley & Sons, 1983.
- *Kalman filtering: Theory and practice using matlab*, M. Grewal and A. Andrews, 3rd Edition, Wiley & Sons, 2008.
- *Linear estimation*, T. Kailath, A. Sayed and B. Hassibi, Prentice Hall, 1999.
- *Probability, Random Variables, and Stochastic Processes*, A. Papoulis and S. U. Pillai, 4th Edition, McGraw-Hill, Inc., 2002.
- *Theory of Point Estimation*, E. Lehmann and G. Casella, Springer-Verlag, 1998.

Software

Matlab/Simulink - version 2019b

Course Webpage

Blackboard will be used for announcements and for sharing course materials.

Course Overview

This course introduces the fundamental concepts of estimation with a focus on Kalman filtering and some of its applications from a system theory perspective. Topics include state-space models with random inputs, optimal state estimation, filtering, prediction and smoothing of random signals with noisy measurements. The course will also cover some extensions of Kalman filtering including extended, unscented and particle Kalman filters. In addition, some computational methods and various applications such as global positioning system, tracking and stochastic system control will be used to exercise the topics covered.

Learning Objectives

Upon successful completion of this course, the student should be able to:

- Understand the basic concepts needed for optimal (state) estimation.
- Design and implement an appropriate Kalman filter for an engineering application.

Grading Policy

Homeworks - 25 % (weekly)
Midterm Exam 1 - 25 % (Date: TBD - second week of February)
Midterm Exam 2 - 25 % (Date: TBD - last week of March)
Final Exam - 25 % (May 5, 2020 from 1:30pm to 4:15pm)

Final grades will be issued according to the traditional grading scheme with these (lower) thresholds:

$$A+ = 97, A = 93, A- = 90, B+ = 87, B = 83, B- = 80, C+ = 77, C = 73, C- = 70, \text{ and so on.}$$

This scheme may be modified. Such modification will be explained before starting the course's first lecture. All graded work should be reviewed promptly by the students. Any questions in regard to potential grading errors should be brought to the attention of the instructor within one week after the assignment is reviewed in class or solutions are posted. Clearly document in writing what you believe the error to be and attach that to the original work.

Course Policies

1. On average homework will be assigned once a week with solutions posted the following week. Homework must be turned in through blackboard before the due date and time allowed. Only ONE random problem from the homework will be graded.
2. Late assignments will not be accepted unless previously discussed with the instructor and only under very special circumstances. No homework will be accepted after solutions are posted.
3. The lowest homework grade will be dropped in computing the overall average.
4. Some homeworks can become project-based.
5. Student are responsible for reviewing the topics listed in the course outline below after each lecture is given. It will not be possible to cover every topic in detail during lectures. Therefore, you should use the course textbook and the other references provided for reinforcing those topics. However, plenty of practice problems and in-class solutions will be provided in order to ensure the transfer of knowledge and its proficiency.
6. The course webpage (Blackboard) is the clearinghouse for all information concerning the course. It will be updated frequently, so check it first when you have any question or concern about the course.
7. Interaction between instructor and students is strongly encouraged. Alternative ways of communication could potentially be set in order to ensure student concerns and doubts are clarified.

Course Outline (tentative)

1. **Linear Systems** (review)
   - Continuous and discrete time systems
   - Basic system operations
   - Nonlinear systems, discretization and linearization
   - Controllability and Observability
   - Linear quadratic regulator and its dual
2. **Probability, random processes and systems** (review)
   - Basic notions of probability
   - Random variables and random processes
   - Linear systems driven by random processes
3. **Estimation**
   - Least squares estimation
   - Bayesian estimation
   - Wiener filtering
   - Propagation of states and covariances
4. **Kalman filtering**
   - The discrete Kalman filter
   - Alternate formulations

- Some generalizations (process correlation and constraints)
- The continuous Kalman filter
- Optimal smoothing

5. **Kalman filtering Extensions**
    - The extended Kalman filter
    - The unscented Kalman filter
    - The particle Kalman filter

Important dates

- First Day of Classes - Date: Jan 14.
- Last Day to Add Classes without Instructor Permission - Date: Jan 17.
- Add/Drop, Pass/No Pass, Audit Deadline - Date: Jan 27.
- Last Day to Withdraw - Date: March 27.
- First Midterm - Date: second week of February.
- Second Midterm - Date: last week of March.
- Spring Recess - Date: March 9-13.
- Last Day of Classes - Date: Apr 30.
- Final Exam - Date: May 5.

Academic Integrity

Any students found giving and/or receiving assistance on Exams or Quizzes will receive a zero score on that assignment. That being said, students are encouraged to work together and to exchange ideas when working on their labs. Students must be sure to reference their work properly, including all web sources. UVM's policy on academic integrity is clearly defined and can be found at `http://www.uvm.edu/ uvmppg/ppg/student/acadintegrity.pdf`

ADA

In keeping with University policy, any student with a documented disability interested in utilizing accommodations should contact SAS, the office of Disability Services on campus. SAS works with students and faculty in an interactive process to explore reasonable and appropriate accommodations, which are communicated to faculty in an accommodation letter. All students are strongly encouraged to meet with their faculty to discuss the accommodations they plan to use in each course. A student's accommodation letter lists those accommodations that will not be implemented until the student meets with their faculty to create a plan. Please visit the following site for contact information. `html://www.uvm.edu/academicsuccess/student_accessibility_services`

Religious Holidays

Students have the right to practice the religion of their choice. Students should submit in writing to the instructor by the end of the second full week of classes their documented religious holiday schedule for the semester. An arrangement could then be made to make up the missed work.

Alcohol/Cannabis

As a faculty member, I want you to get the most you can out of this course. You play a crucial role in your education and in your readiness to learn and fully engage with the course material. It is important to note that alcohol and cannabis have no place in an academic environment. They can seriously impair your ability to learn and retain information not only in the moment you may be using, but up to 48 hours or more afterwards. It is my expectation that you will do everything you can to optimize your learning and to fully participate in this course.