Course Syllabus for **AOE 5784, Model-Based Estimation and Kalman Filtering.** **Fall 2024**

Instructor: Prof. Mark L. Psiaki, 335 Durham Hall, phone: 231-1907, e-mail: mlpsiaki@vt.edu
Lecture: Tuesdays 8-9:15 a.m., Wednesdays 8-8:50 a.m., & Thursdays 8-9:15 a.m. in McBryde Hall Room 316 and via Zoom at https://virginiatech.zoom.us/j/85627922781?pwd=wwPNjwGVmu6O4PhV2hsov6KcqFua6K.1, Meeting ID: 856 2792 2781, Passcode: 236383. The Zoom lectures will be recorded and posted to the course Canvas site for students who cannot attend in-person and who cannot attend the synchronous Zoom versions.
Office Hours: 1:30-2:30 p.m. Tuesdays & Thursdays in Durham Hall 335 and via Zoom at https://virginiatech.zoom.us/j/83377601356?pwd=KsYAa7ILtoHebjjuCbGgLgVR5YCImj.1, Meeting ID: 833 7760 1356, Passcode: 232214.
Course Web Access: Canvas course AOE_5784_91176_202409 (in-person)
Canvas course AOE_5784_91213_202409 (online)

Prerequisites: Linear algebra, differential equations, undergraduate-level probability theory, MATLAB programming, & AOE 5744/ME 5544/ECE 5744 or AOE 5754/ECE 5754/ME 5554 (either may be taken simultaneously with AOE 5784) Course is run primarily for M.S./Ph.D. students. Others may participate only with the understanding that the work load will be high.

Text:

Bar-Shalom, Yaakov, Li, X.-Rong, and Kirubarajan, Thiagalingam, *Estimation with Applications to Tracking and Navigation*, J. Wiley & Sons, (New York, 2001).

Additional references:

Anderson, B.D.O. and Moore, J.B., *Optimal Filtering*, Prentice-Hall, (Englewood Cliffs, N.J., 1979).

Bierman, G.J., *Factorization Methods for Discrete Sequential Estimation*, Academic Press, (New York, 1977).

Brown, R.G., and Hwang, P.Y.C., *Introduction to Random Signal Analysis & Kalman Filtering: With Matlab Exercises & Solutions, 3rd Edition*, J. Wiley & Sons, (New York, 1997).

Chui, C.K. and Chen, G., *Kalman Filtering with Real-Time Applications, 3rd Edition*, Springer-Verlag (New York, 1999).

Crassidis, J.L., and Junkins, J.L., *Optimal Estimation of Dynamic Systems*, Chapman & Hall/CRC, (New York, 2004).

Gelb, A., ed., *Applied Optimal Estimation*, MIT Press, (Cambridge, MA, 1974).

Gill, P.E., Murray, W., and Wright, M.H., *Practical Optimization*, Academic Press, (New York, 1981).

Haykin S., ed., *Kalman Filtering and Neural Networks*, J. Wiley & Sons, (New York, 2001).

Junkins, J.L., *An Introduction to Optimal Estimation of Dynamical Systems*, Sijthoff & Noordhoff (Alphen aan den Rijn, 1978).

Mendel, J.M., *Lessons in Digital Estimation Theory*, Prentice-Hall, (Englewood Cliffs, N.J., 1987).

Stengel, R.F., *Optimal Control and Estimation*, Dover (New York, 1994).

Grade Policy:

Take-home prelim #1	30 %
Take-home prelim #2	30 %
Take-home final exam	40 %

Synopsis: This course covers a variety of ways in which models and experimental data can be used to estimate model quantities that are not directly measured. In other words, this course concerns itself with methods for solving the class of inverse problems that take the following form: given partial information about a system, what is the behavior of the whole system? The two main estimation methods that are presented are a) batch least-squares-type estimation for general problems and b) Kalman filtering for dynamic system problems. The course also deals with the issue of observability, which amounts to a consideration of whether a given inverse problem has a unique solution, and it briefly covers the concept of statistical hypothesis testing. Techniques for linear and nonlinear models are taught. Both theory and application are presented.

Examples from the course are drawn from various fields, possibly including particle and rigid-body dynamics, GPS-based navigation, and signal tracking via phase-locked loops.

From time to time problems will be assigned. Each student should solve all of these problems. None of them will get handed in, but some of them (perhaps in slightly modified form) will comprise the take-home exams. Students are free to discuss the assignments with each other, except that they cannot discuss them during the time period of a take-home exam. Therefore, it behooves each student to work each problem and discuss it with classmates before it finds its way onto an exam. Students are not permitted to share MATLAB software with each other at any time during the course, neither in electronic form nor in hardcopy form. It is permitted to discuss programming strategies and to share hand-written equations that describe parts of software.

AOE 5784 Syllabus

Dates	Topics	Reading*
8/27-8/29	Organization & intro. to estimation	1.1-1.2
	Review of Linear Algebra	1.3
9/3-9/11	Review of probability and statistics	1.4-1.5
9/12	Estimation Basics	2
9/17-9/19	No lecture due to Prof. Psiaki conference travel	-
9/24	Estimation Basics (continued)	2
9/25-9/26	Linear Parameter Estimation	3
10/1-10/9	Nonlinear least squares algorithms & relevant concepts from general unconstrained nonlinear programming	3.7 & Gill et al. 3.1, 3.2, 4.1, 4.3, 4.7
10/10-10/15	Stochastic Linear System Models	4
10/16-10/17	Kalman Filters for Discrete-Time Systems	5
10/22	Alternate derivation of the Discrete-Time Kalman Filter	-
10/23-10/24	Kalman Filter Analyses	-
10/29-10/30	Kalman Filter Consistency & Initialization	5
10/31-11/12	Information Filtering & Square-Root techniques	7, Bierman
	Introduction to Smoothing	8.6, Bierman 10
11/13-11/19	Nonlinear difference eqs. from nonlinear differential eqs.	-
	Nonlinear Estimation & Extended Kalman Filtering	10
11/20-11/21	Unscented Kalman Filter	Article #
	Particle Filters	Article **

* All readings are in Bar-Shalom unless otherwise indicated.

Wan, E.A., and van der Merwe, R., "The Unscented Kalman Filter," *Kalman Filtering and Neural Networks*, S. Haykin, ed., J. Wiley & Sons, (New York, 2001), pp. 221-280. (Book is available in Library Reserve and on-line via VT Library catalog.)

11/26-11/28	Thanksgiving break	
12/3-12/10	Particle Filters (continued)	Article**
12/11	Gaussian Mixture Filters	Handouts

Graduate Honor System Requirements: Work in this course falls under that Virginia Tech Graduate Honor System, which is described in detail at:

http://graduateschool.vt.edu/academics/expectations/graduate-honor-system.html

Compliance with the Graduate Honor Code requires that all graduate students exercise honesty and ethical behavior in all their academic pursuits here at Virginia Tech, whether these undertakings pertain to study, course work, research, extension, or teaching. The fundamental beliefs underlying and reflected in the Graduate Honor Code are that (1) to trust in a person is a positive force in making a person worthy of trust, (2) to study, perform research, and teach in an environment that is free from the inconveniences and injustices caused by any form of intellectual dishonesty is a right of every graduate student, and (3) to live by an Honor System, which places a positive emphasis on honesty as a means of protecting this right, is consistent with, and a contribution to, the University's quest for truth.

All assignments, quizzes, and exams submitted shall be considered "graded work" and all aspects of your coursework are covered by the Honor Code. All such work is to be completed individually unless otherwise specified. Students are free to discuss general principles and approaches with each other when preparing homework solutions, but they are not permitted to view each other's written or typed work, including any Matlab code that may have been generated in the process of completing an assignment.

Commission of any of the following acts shall constitute academic misconduct. This listing is not, however, exclusive of other acts that may reasonably be said to constitute academic misconduct.

A. CHEATING

Cheating includes the intentional use of unauthorized materials, information, notes, study aids or other devices or materials in any academic exercise, or attempts thereof.

B. PLAGIARISM

Plagiarism includes the copying of the language, structure, programming, computer code, ideas, and/or thoughts of another and passing off the same as one's own original work, or attempts thereof.

C. FALSIFICATION

Falsification includes the statement of any untruth, either verbally or in writing with respect to any element of one's academic work, or attempts thereof.

D. FABRICATION

** Arulampalam, M.S., Maskell, S., Gordon, N., and Clapp, T., "A Tutorial on Particle Filters for Online Nonlinear/Non-Gaussian Bayesian Tracking," *IEEE Transactions on Signal Processing*, Vol. 50, No. 2, Feb. 2002, pp. 174-188. (Journal is available on-line via VT Library catalog.)

Fabrication includes making up data and results, and recording or reporting them, or submitting fabricated documents, or attempts thereof.

E. MULTIPLE SUBMISSION

Multiple submission involves the submission for credit—without authorization of the instructor receiving the work—of substantial portions of any work (including oral reports) previously submitted for credit at any academic institution, or attempts thereof.

F. COMPLICITY

Complicity includes intentionally helping another to engage in an act of academic misconduct, or attempts thereof.

G. VIOLATION OF UNIVERSITY, COLLEGE, DEPARTMENTAL, PROGRAM, COURSE, OR FACULTY RULES

The violation of any University, College, Departmental, Program, Course, or Faculty Rules relating to academic matters that may lead to an unfair academic advantage by the student violating the rule(s).