

E SC (PHYS) 597A, Neural Control Engineering

New 3 credit course, Fall 2008

Monday 3:35 pm - 5:55 pm in 121 EES

Instructor: Steven Schiff

Prerequisites: None

- The ability to use formal control theory to observe and control neuronal systems is rapidly becoming more feasible as our models of neural systems become more realistic and as our advances in nonlinear Kalman filtering become more sophisticated. This course will explore the cutting edge of nonlinear state estimation of neuronal systems, and the construction of control algorithms based on that state estimation. We will introduce several canonical neuroscience models, which represent experimental systems that can be controlled: the Hodgkin-Huxley equations, their reduction with the Fitzhugh-Nagumo equations, the Wilson-Cowan model of cortex, and recent models of Parkinson's disease. We will then apply nonlinear state estimation to measurements from such systems and construct control algorithms that interact with such models. A final project will employ these techniques, and each student will solve a open and novel problem in the control engineering of neuronal systems. This course is relevant to advanced undergraduate and graduate students in Engineering, Mathematics, Physics, Biology, and the Integrated Biology graduate programs such as Neuroscience.
- The following major topics will be covered:
 - Introduction to the Linear Kalman filter
 - The extended and nonlinear unscented Kalman filter
 - The Hodgkin-Huxley neuron.
 - The reduced Hodgkin-Huxley model: The Fitzhugh-Nagumo equations
 - Observability of the Fitzhugh-Nagumo neuron
 - Control of the Fitzhugh-Nagumo neuron
 - Analyzing pattern formation in cortex
 - The Wilson-Cowan equations of cortex
 - Observing and controlling cortical patterns of activity
 - Models of Parkinson's disease
 - Observing and controlling models of Parkinson's disease
 - Data Assimilation – The Consensus Set
 - Model Adequacy
 - Empirical Models – POD and ARIMA
 - Electrical Feedback Control in Neuronal Systems
 - Brain Machine Interfaces
 - Extending the Frontier – Final project solving a novel problem.

Grades will be based upon the preparation and effectiveness of the literature presentations (20%), an interim computational project demonstrating an understanding of the basic computational techniques (15%), and a final project (65%). The final project requires writing a scientific paper that uses the methods presented in this course to solve a novel problem in computational neural control. A series of open problems will be offered to the students to select, or an approved project of the students' choice.

- Relationship of Course to Other Courses.
 - This course forms a third new offering in the Neural Engineering track in Engineering Science and Mechanics. The other courses in ESM recently development include: E SC 497, Introduction to Brain Machine Interfaces, and E SC 597, Introduction to Neural Engineering: Fundamentals of Interfacing with Brain.
 - Other related courses include: Applied Optimal Estimation (AERSP 597), Modeling of Dynamic Systems (M E 450), Experimental Nonlinear Dynamics (E MCH 597), Introduction to Computational Neurosciences (PHYS 597).
 - Well prepared undergraduate students with strong quantitative backgrounds in the College of Engineering (Aerospace Engineering, Computer Science & Engineering, Mechanical Engineering), College of Science (Biology, Mathematics, and Physics), as well as graduate students from the Interdisciplinary Graduate Degree Programs (Bioengineering, Biosciences, and Neuroscience), are welcome to enroll at the discretion of the instructor.
- Textbook: D. Simon, Optimal State Estimation, Wiley Interscience, 2006
Optional Textbook: S. Thrun, Probabilistic Robotics, MIT Press, 2006

Table of Contents

- 1. Linear Kalman Filtering 4**
 - 1.1. Perspective 4**
 - 1.2. Examples 4**
 - 1.2.1. Position.....4
 - 1.2.2. Least Squares and Gauss.....6
 - 1.2.3. Recursive Least Squares6
 - 1.2.4. Blood Pressure6
 - 1.2.5. Kalman Filtering Position and Blood Pressure6
 - 1.2.6. Uncertain Science in a Bayesian World6
 - 1.2.7. Why Neuroscience Never Crossed Our Minds From 1960-20006
 - 1.3. Key References 6**
 - 1.3.1. Kalman 19606
 - 1.3.2. Mayberg.....6
 - 1.3.3. Strang.....6
 - 1.3.4. Wilke and Berliner.....6
 - 1.3.5. Simon.....6
 - 1.4. Resources 6**
 - 1.4.1. Matlab Tutorial.....6
- 2. Nonlinear Kalman Filtering 8**
 - 2.1. EKF.....8**
 - 2.2. UKF8**
 - 2.3. Particle and Monte Carlo Techniques.....8**
 - 2.4. Key References8**
 - 2.4.1. Julier and Uhlman, 19978
 - 2.4.2. Thrun et al 2006.....8
- 3. Fitzhugh-Nagumo Equations..... 8**
 - 3.1. Voss’ Algorithm – UKF and FN Dynamics.....8**
 - 3.2. Key References8**
 - 3.2.1. Nagumo8
 - 3.2.2. Voss, Timmer, Kurths 20048
- 4. Hodgkin Huxley Equations 8**
 - 4.1. Key References8**
 - 4.1.1. Hodgkin and Huxley 1952 a-d.....8
 - 4.1.2. Prinz (dynamic clamp)8
 - 4.1.3. Ullah and Schiff 2008.....8
- 5. Wilson-Cowan Equations 8**
 - 5.1. Key References8**
 - 5.1.1. Wilson and Cowan 1972, 19738
 - 5.1.2. Pinto and Ermentrout 2001a,b8
 - 5.1.3. Huang et al 2004.....8
 - 5.1.4. Schiff and Sauer 2008.....8
- 6. Parkinson’s Disease 9**
 - 6.1. Key References9**

6.1.1.	Terman et al 2002.....	9
6.1.2.	Rubin and Terman 2004.....	9
7.	Data Assimilation – The Consensus Set.....	9
7.1.	Key References.....	9
7.1.1.	Wilke and Berliner 2007.....	9
7.1.2.	Sauer and Schiff 2008.....	9
8.	Model Adequacy.....	9
8.1.	Key References.....	9
8.1.1.	Toth et al 2007.....	9
9.	Empirical Models – POD.....	10
9.1.	Key References.....	10
9.1.1.	Sirovich Tutorial.....	10
9.1.2.	Schiff et al 2007.....	10
10.	Electrical Feedback Control in Neuronal Networks.....	10
10.1.	Key References.....	10
10.1.1.	Gluckman et al 1996, 2001.....	10
11.	Brain Machine Interfaces.....	10
11.1.	Key References.....	10
11.1.1.	Wu et al - Kalman.....	10
11.1.2.	Wu et al – Particle.....	10
11.1.3.	Srinivassan and Brown.....	10
11.1.4.	Murphy – Switching Kalman Filters.....	10
11.1.5.	Kamrunnihar et al 2008.....	10
12.	Open Problems.....	10
12.1.	Galerkin Projection in WC.....	10
12.2.	Potassium Dynamics in WC, FN, PD.....	10
12.3.	Assimilation:.....	10
12.3.1.	WC ->FN.....	10
12.3.2.	FN-> WCV.....	10
12.3.3.	HH-> FN.....	10
12.3.4.	FN-> HH.....	10
12.4.	Fundamental + Empirical.....	10
12.5.	Optimize.....	10
12.5.1.	Process and Observation Noise.....	11
12.5.2.	Covariance Inflation.....	11
12.5.3.	Square Root Filtering.....	11
12.6.	Multimodal Filtering.....	11
12.6.1.	Mixture of Gaussians.....	11
12.6.2.	Particle Filtering.....	11
12.7.	Seizure Prediction.....	11
12.7.1.	Linking Hidden Markov with Discrete Kalman Filter.....	11
12.8.	BYO Model.....	11
13.	Bibliography.....	12
14.	Index.....	23