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 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

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