Hybrid Dynamical Systems (CMPE 246)
Winter 2015

Instructor Information:
Prof. Ricardo G. Sanfelice
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General Information:

- Meetings: Tuesday and Thursday 4pm to 5:45pm (01/05/15 - 03/16/15), J. Baskin Engr 169
- Office hours: T 6:00pm to 7:00 pm and Th 3:00pm to 4:00 pm (both at E2-321)

Course Description:
Driven by recent technological advances and user specifications, most systems of today combine digital and analog devices, humans interacting with embedded computers, software distributed through networks, etc. As a result, they have state variables evolving both continuously and discontinuously due to features such as events, logic transitions, and impacts; they rely on algorithms implemented in embedded computers, which are interfaced with the plants through analog/digital and digital/analog devices; and they involve sensing and actuation through networks using communication protocols. Due to the presence of two types of dynamics, continuous and discrete, these systems are called hybrid dynamical systems.

This course provides an introduction to hybrid dynamical systems and presents advances tools for their analysis. After a short review of several mathematical concepts, a general modeling framework is introduced and exercised in several applications. A definition of solutions (or trajectories) to these systems is introduced next and their structural properties are investigated. A phenomenon unique to hybrid systems, called Zeno behavior, is introduced and discussed. Definitions of stability and convergence are presented next. Sufficient conditions for convergence to and asymptotic stability of equilibrium sets are given first for the linear case, which consist of invariance and eigenvalue conditions, respectively, and then for the nonlinear case, which are Lyapunov based. A characterization of the robustness properties induced by asymptotic stability follow and is illustrated with several applications. Throughout the course, the students will be guided on methods for simulation of hybrid systems and encouraged to apply them to several applications.

Catalog Description: Graduate-level course on modeling and analysis of hybrid dynamical systems. Modeling of hybrid systems, concept of solutions, Zeno behavior, equilibrium sets, stability, convergence, Lyapunov-based conditions, robustness, and simulation. Students will be guided on methods for simulation and encouraged to apply them to several applications. Enrollment restricted to graduate students.

Topics: Modeling; Definition of solutions; Zeno behavior; Equilibrium sets; Stability and convergence; Nominal robustness; Numerical simulation. The content will be mainly theoretical. Applications will be on modeling and analysis of hybrid systems in the context of unmanned aerial vehicles, robotic manipulators, hard-disk drive, mechanical systems with impacts, impulsively-coupled oscillators, cellular networks, and others.

Prerequisites: The course is self contained. Students are expected to have basic background on differential equations, calculus, linear algebra, and feedback control (CMPE 241 or equivalent). Knowledge of Matlab/Simulink will be useful.

Mandatory course requirements:
CMPE 241: Introduction to Feedback Control Systems

Suggested additional courses (enrollment encouraged if offered concurrently):
CMPE 240: Introduction to Linear Dynamical Systems

Structure and Grading Scheme:

- Homework will account for **20%** of final grade.
- Midterm (take home, date TBD), **40%** of final grade.
- Final project written report, first version, will consist of a conference paper, March 9, 11:59pm, **5%** of final grade.
- Formal review of one final project written report (first version) by your peers, March 10, 11:59pm, **5%** of final grade.
- Formal response to the reviewers of your final project written report (first version), March 11, 11:59pm, **5%** of final grade.
- Final presentations, March 13, 9am-noon, **5%**.
- Final version of report, March 20, 11:59pm, **20%**.

The "break points" dividing letter grades will be determined by the Instructor at the end of the quarter, based on the overall performance of the class and other relevant factors. Class participation will be taken into consideration when determining boundary cases.

Grading homework and exam papers is a difficult task, and errors or misjudgments occasionally occur. Any student who feels that his or her paper has not been graded properly may request that the paper be regraded. However, all such requests must be made no later than one week after the assignment has been returned. The complete paper will be reexamined.

Course Discussion Group: Our Google group will be the preferred way to communicate for questions about class material. For personal questions, please email me directly. Remember that there is no wrong question to ask, so please do ask questions. Please request access to the group

`https://groups.google.com/forum/#!forum/hybridsystemsclass`

using your gmail-sponsored UCSC email. I strongly suggest to configure it to notify you via email when new posts are made. Please check for announcements posted via the discussion group. An immediate response is not guaranteed, but you should expect to get one within 24hs when your post is made or your email arrives to the instructor's email inbox Monday to Friday during working hours.

References:

- **Main reference (textbook)**: Goebel, R.; Sanfelice, R.G.; Teel; A.R., Hybrid Dynamical Systems: Modeling, Stability, and Robustness. Princeton University Press, 2012.

  https://hybrid.soe.ucsc.edu/hsbook

- Goebel, R.; Sanfelice, R.G.; Teel; A.R., Hybrid Dynamical Systems, IEEE Control Systems Magazine, pp. 28-93, April 2009.

  https://hybrid.soe.ucsc.edu/files/preprints/34.pdf

- Franklin, G.; Powell, J. & Emami-Naeini, A. Feedback Control of Dynamic Systems 4th. Edition Prentice Hall, 2002.

- Chi-Tsong Chen, Linear System Theory and Design, Oxford University Press US, 1998

- H. Khalil, Nonlinear Systems, Prentice Hall, 2002.