CSCI-513: Autonomous Cyber-Physical Systems

Units: 4
Fall

Location: TBD

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[Response within 24 hours]

Course Description

Cars, ground and aerial robots, and medical devices have all traditionally relied on a human operator. By bestowing autonomy on these systems, we hope to replace the human operator or reduce their role by the use of intelligent software agents. While classical software design typically involves reasoning about concerns only in the cyber-space, autonomous systems are usually cyber-physical systems, i.e. they involve a set of physical components, e.g., mechanical, electrical or biological component being controlled and monitored by software.

This course introduces you to the design and analysis of such autonomous cyber-physical systems (ACPS) from a computer science and formal reasoning perspective. This includes: formal models of computation for ACPS, including models for the real world environments/components as well as models for the control software, formal languages for specification and testing of ACPS, and basics of linear and nonlinear control theory as used for ACPS. In the second part of the course, we will study some of the main components used in autonomy such as software components for perception, planning, navigation, and AI-based techniques for control design such as reinforcement learning. The homework assignments will be written exercises, while two mini-projects will require coding in Python as well as Matlab/Simulink. The mini-projects include an implementation of a simple self-driving vehicle subsystem, and an assignment about programming unmanned aerial vehicles (in the Matlab environment). The course will position you to gain the skills required for industrial development of autonomous systems, and will also enable you to think about research problems in autonomy.

Learning Objectives and Outcomes

- Gain basic familiarity with Autonomous Cyber-Physical Systems (ACPS)
- Learn how to develop software for an ACPS using a model-based development approach
- Learn how to write formal requirements for ACPS models and perform testing
- Learn basics of simulation-based testing and falsification
- Learn basics of autonomous systems, and the autonomous systems software stack

Recommended Preparation:

a) Knowledge of mathematical logic at the level of CSCI 170
b) Basic Knowledge of Matlab®/Simulink® recommended
c) Basic Knowledge of Python recommended

Course Notes:

Course Structure. In this course, most of the teaching will be accomplished through lectures. In addition, we will have the following elements:

1. **Homework assignments:** We will have 2 written homework assignments through the semester.
2. **Mini-Projects:** We will have two coding projects through the semester.
3. The course will have a project, with structure outlined below

Project Structure. The purpose of the class project is for you to practice model-based development of a cyber-physical system application and adding some elements of autonomy to the system. Students will work in teams of two (in exceptional cases in single-person teams or teams of three). The general expectation from the project is for each team to demonstrate their understanding of the course through a software or hardware application of autonomy, or explore a suitable research topic with discussion with the instructors.

Project Deliverables:

a) Presentations:
   When: Students will perform two presentations during the course. In Week 7, each team will give a 10-minute presentation on the mid-term project progress. In the finals week, each team will give a 20-minute final presentation. There will be two 2-hour slots reserved for the final presentation during the finals week (or one 4-hour slot).
   Format: The mid-term presentation is expected to contain the following key elements: (a) review of related work (not exceeding 30% of the presentation), (b) proposed CPS application and associated problem, (c) timeline for expected results. The final project presentation is expected to contain the following elements: (a) summary of problem definition and solution, (b) key results and findings, (c) conclusions and related work.
b) **Report**: Students will submit a final report by a specified deadline in the finals week. The report will be expected to be single-column text, single-spaced pages in font size not exceeding 11pt. The report is expected to be at least 8 pages and at most 10 pages, excluding references.

Project Timeline:

Week 2	Team member identification
Week 4	Project Proposal Due
Week 7	Mid-Term Project Progress
Finals Week	Final Presentation & Report

Grading Breakdown for the Project (Total weight = 40%):

Proposal Document	5%
Mid-term Project Progress	10%
Final Report/Demo	20%
Final Presentation	5%

Technological Proficiency and Hardware/Software Required
Students are highly encouraged to be well-versed with Matlab® and Simulink®. Homework assignments will expect students to write Matlab® code and use Simulink®

models. Knowledge of Python would be beneficial if students plan to do their projects using Python libraries such as Tensorflow or PyTorch.

Required Readings and Supplementary Materials

The course does not have a prescribed textbook. The following books are recommended for supplemental reading:

1) Principles of Cyber-Physical Systems by Rajeev Alur, MIT Press.
2) Introduction to Embedded Systems - A Cyber-Physical Systems Approach, by Lee & Seshia, Second Edition, MIT Press. http://leeseshia.org
3) Principles of Model Checking by Christel Baier and Joost-Pieter Katoen, MIT Press.
4) Cyber-Physical Systems by Raj Rajkumar, Dioniso de Niz, Mark Klein, Addison-Wesley.

Description and Assessment of Assignments

There will be 3 written assignments and two coding assignments (using Matlab®/Simulink®). Assignments will be assessed for the completeness and correctness of answers. Coding assignments will be graded using instructor-provided grading scripts. Partial credit will be assigned wherever applicable.

Grading Breakdown

Including the above detailed assignments, how will students be graded overall? Participation should be no more than 15%, unless justified for a higher amount. All must total 100%.

Category		**Points**	**% of Grade**	
Homeworks/ Mini-Projects	HW1	100	10	55
	HW2	100	10	
	MP1	100	20	
	MP2	100	15	
Project		100		40
Participation		100		5
TOTAL				100

Grading Scale (Example)

Course final grades will be determined roughly using the following scale

A 90-100
A- 85-89
B+ 80-84
B 75-79
B- 70-74
C+ 65-69
C 60-64
F 59 and below

Assignment Rubrics

1. Homework assignments will be graded for correctness of answers and provided explanation/proofs. Partial credit will be given wherever applicable.
2. Projects will be graded for the technical depth, novelty, repeatability of the experiment performed. Projects with a greater use of the concepts learned during the course will receive a higher grade.
3. The class will use Slack for online discussions related to the concepts covered in the class. Students will be expected to ask and answer questions during in-class lectures and participate in discussions on Slack. The participation grade will be assessed on both forms of student involvement in the course.

Assignment Submission Policy

Assignments are expected to be turned in to the instructor/TA by 11:59.59pm Pacific Time on the deadline. There will be a 5% penalty for every late day for 7 days. Assignments submitted 7 days after the deadline will be returned with a zero grade.

Grading Timeline

Graded assignments will be returned to students in a time period not exceeding 2 weeks from the submission of the assignment.

Course Schedule: A rough weekly Breakdown

Please see up-to-date schedule at:
https://jdeshmukh.github.io/teaching/cs513-autocps-fall-2021/schedule.html

	Topics/Daily Activities	**Deliverable/ Due Dates**
Week 1	Course overview, Introduction to Models of Computation and Finite State Machines	
Week 2	Timed and Dynamical Systems	
Week 3	Labor Day	Team Member Identification for Projects
Week 4	Hybrid Dynamical Systems	HW1 posted
Week 5	Linear control, Nonlinear control, Observer Design Design	HW1 due, MP1a posted
Week 6	Temporal Logic Formalisms	
Week 7	Temporal Logic : Testing and Falsification	
Week 8	Safety Verification	MP1a due
Week 9	Probabilistic Models, Probabilistic Verification	HW2 posted
Week 10	Project Proposals, Schedule Overflow	Project Proposals

		Due
Week 11	Path Planning	HW2 due
Week 12	Sensing & Perception	MP1b posted, MP2 posted
Week 13	Reinforcement Learning and Deep RL	MP1b due
Week 14	Schedule Overflow, Advanced Topics in Autonomy	
Week 15	Communication, Coordniation and Co-operation, CPS security	MP2 due
Finals Week	Final Project Presentations	Final Project Report Due

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, policy.usc.edu/scientific-misconduct.

Support Systems:

Counseling and Mental Health - (213) 740-9355 – 24/7 on call
studenthealth.usc.edu/counseling
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

National Suicide Prevention Lifeline - 1 (800) 273-8255 – 24/7 on call
suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

Relationship and Sexual Violence Prevention and Services (RSVP) - (213) 740-9355(WELL), press "0" after hours – 24/7 on call
studenthealth.usc.edu/sexual-assault
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED)- (213) 740-5086 | Title IX – (213) 821-8298
equity.usc.edu, titleix.usc.edu
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Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298
usc-advocate.symplicity.com/care_report
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity |Title IX for appropriate investigation, supportive measures, and response.

The Office of Disability Services and Programs - (213) 740-0776
dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.