TO: The Faculty of the College of Engineering

FROM: School of Electrical and Computer Engineering of the College of Engineering

RE: New Graduate Course, ECE 60268 Hybrid Systems: Theory and Applications

The faculty of the School of Electrical and Computer Engineering has approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

ECE 60268 Hybrid Systems: Theory and Applications
Sem. 2, Lecture 3, Cr. 3.

Prerequisite: ECE602 (or AAE564 or equivalent) and MA511 (or equivalent)

Prerequisite by Topic: Feedback control systems; linear system theory; linear algebra.

Description: The revolution in digital technology has fueled a need for design techniques that can guarantee safety and performance specifications of systems that couple discrete logics with analog physical environment. Such systems can be modeled by hybrid systems, which are dynamical systems that combine continuous-time dynamics modeled by differential equations and discrete-event dynamics modeled by finite automata. This course will present an overview of the recent advances in modeling, analysis, control, and verification of hybrid systems. Topics covered include: continuous-time and discrete-event models; computational tools; reachability analysis; safety specifications and model checking; (Lyapunov) stability analysis and verification tools; optimal control; stochastic hybrid systems; numerical simulations; and a range of engineering applications.

Reason: In the past two decades, research on hybrid systems has seen a tremendous increase due to the fact that many modern control systems, especially computer controlled systems, can only be modeled by hybrid systems but not the classical dynamical systems models. Outcomes from this research have been successfully applied to a wide spectrum of engineering applications. This course will introduce to the students the basic knowledge of the hybrid system modeling framework and the typical methods for their analysis and controller design, to prepare them for a career of control practitioners to deal with the increasingly wider and more challenging control applications nowadays. Current control curriculum at Purdue is no longer adequate for this purpose. Due to the diverse applications of hybrid systems, the course will also be of interest to students from other areas, such as computer engineering, communication and signal processing, etc.

This course will be a welcome addition to the existing control curriculum at ECE. It takes as a prerequisite and will be a natural extension of ECE 602 (Lumped Linear Systems), which is the core course of the AC area. It will also be a good complement to other ECE graduate control courses (e.g., ECE 680, ECE 675). The offering of this course can partially address a common complaint by AC graduate students, namely, that there is an insufficient number of 600-level AC courses being offered to fulfill their plan of study.

Michael R Melloch

Michael R. Melloch, Associate Head
School of Electrical and Computer Engineering

Office of the Registrar
FORM 40G REV. 4/13

PURDUE UNIVERSITY
REQUEST FOR ADDITION, EXPIRATION,
OR REVISION OF A GRADUATE COURSE
(50000-60000 LEVEL)

DEPARTMENT: Electrical and Computer Engineering EFFECTIVE SESSION: Spring 2017

INSTRUCTIONS: Please check the items below which describe the purpose of this request.

- [x] 1. New course with supporting documents (complete proposal form)
- [ ] 2. Add existing course offered at another campus
- [ ] 3. Expiration of a course
- [ ] 4. Change in course number
- [ ] 5. Change in course title
- [ ] 6. Change in course credit/type
- [ ] 7. Change in course attributes
- [ ] 8. Change in instructional hours
- [ ] 9. Change in course description
- [ ] 10. Change in course requisites
- [ ] 11. Change in semesters offered
- [ ] 12. Transfer from one department to another

PROPOSED:
Subject Abbreviation: ECE
Course Number: 60268
Long Title: Hybrid Systems: Theory and Applications
Short Title: Hybrid Systems: Theory & App
Abbreviated title will be entered by the Office of the Registrar if omitted. (30 CHARACTERS ONLY)

EXISTING:
Subject Abbreviation:
Course Number:

TERMS OFFERED
Check All That Apply:
- [x] Fall
- [ ] Spring
- [ ] Summer

CAMPUS(ES) INVOLVED
- [ ] Calumet
- [ ] Cont Ed
- [ ] Ft. Wayne
- [ ] Indianapolis
- [ ] N. Central
- [ ] Tech Statewide
- [x] W. Lafayette

CREDIT TYPE
1. Fixed Credit: Cr. Hrs. 3.0
2. Variable Credit Range:
   Minimum Cr. Hrs
   (Check One) To [ ] Or [ ]
   Maximum Cr. Hrs
3. Equivalent Credit: Yes [ ] No [x]
4. Thesis Credit: Yes [ ] No [x]

COURSE ATTRIBUTES: Check All That Apply
1. Pass/Not Pass Only [ ]
2. Satisfactory/Unsatisfactory Only [ ]
3. Repeatable [ ]
   Maximum Repeatable Credit: [ ]
4. Credit by Examination [ ]
5. Fees [ ] Coop [ ] Lab [ ] Rate Request
   Include comment to explain fee
6. Registration Approval Type
   Department [ ] Instructor [ ]
7. Variable Title [ ]
8. Honors [ ]
9. Full Time Privilege [ ]
10. Off Campus Experience [ ]

Schedule Type	Minutes Per Mtg	Meetings Per Week	Weeks Offered	% of Credit Allocated
Lecture	75	2	16	100%
Recitation				
Presentation				
Laboratory				
Lab Prep				
Studio				
Distance				
Clinic				
Experiential				
Research				
Ind. Study				
Pract/Observ				

Cross-Listed Courses
AAE 66800

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS):
The revolution in digital technology has fueled a need for design techniques that can guarantee safety and performance specifications of systems that couple discrete logics with analog physical environment. Such systems can be modeled by hybrid systems, which are dynamical systems that combine continuous-time dynamics modeled by differential equations and discrete-event dynamics modeled by finite automata. This course will present an overview of the recent advances in modeling, analysis, control, and verification of hybrid systems. Topics covered include: continuous-time and discrete-event models; computational tools; reachability analysis; safety specifications and model checking; (Lyapunov) stability analysis and verification tools; optimal control; stochastic hybrid systems; numerical simulations; and a

*COURSE LEARNING OUTCOMES:
o Understand the advance of modern operating systems (a)
o Understand and criticize the major approaches in designing and implementing modern operating systems (a) (c)
o Learn the experience in experimenting with modern systems software (a)
o Being able to describe the design of operating systems software, discuss software bugs, and offer insights. (b)(c)

Calumet Department Head — Date	Calumet School Dean — Date	Calumet Director of Graduate Studies — Date
Fort Wayne Department Head — Date	Fort Wayne School Dean — Date	Fort Wayne Director of Graduate Studies — Date
Indianapolis Department Head — Date	Indianapolis School Dean — Date	IUPUI Associate Dean for Graduate Education — Date
North Central Department Head — Date	North Central School Dean — Date	North Central Director of Graduate Studies — Date
Michael R Melloch 10/6/16 West Lafayette Department Head — Date	West Lafayette College/School Dean — Date	Date Approved by Graduate Council — Date
Graduate Area Committee Convener — Date	Graduate Dean — Date	Graduate Council Secretary — Date
		West Lafayette Registrar — Date

OFFICE OF THE REGISTRAR

Supporting Document to the Form 40G
for a New Graduate Course

To: Purdue University Graduate Council

From: Faculty Member: Jianghai Hu

Department: Electrical and Computer Engineering

Campus: West Lafayette

Date:

Subject: Proposal for New Graduate Course

Contact for information if questions arise:

Name: Matt Golden
Phone: 494-3374
Email: goldenm@purdue.edu
Address: EE Building, Room 135

Course Subject Abbreviation and Number: ECE 60268

Course Title: Hybrid Systems: Theory and Applications

Course Description:

The revolution in digital technology has fueled a need for design techniques that can guarantee safety and performance specifications of embedded systems, or systems that couple discrete logics with analog physical environment. Such systems can be modeled by hybrid systems, which are dynamical systems that combine continuous-time dynamics modeled by differential equations and discrete-event dynamics modeled by finite automata. This course will present an overview of the recent advances in modeling, analysis, control, and verification of hybrid systems. Topics covered include: continuous-time and discrete-event models; reachability analysis; safety specifications and model checking; optimal control and differential games; (Lyapunov) stability analysis and verification tools; stochastic hybrid systems; numerical simulations; and a range of engineering applications.

Semesters Offered:

For the benefit of graduate student plan of study development, how frequently will this prototype be offered? Which semesters?
Fall even years

A. Justification for the Course:

Provide a complete and detailed explanation of the need for the course (e. g., in the preparation of students, in providing new knowledge/training in one or more topics, in meeting degree requirements, etc.), how the course contributes to existing majors and/or concentrations, and how the course relates to other graduate courses offered by the department, other departments, or interdisciplinary programs.

In the past two decades, research on hybrid systems has seen a tremendous increase due to the fact that many modern control systems, especially computer controlled systems, can only be modeled by hybrid systems but not the classical dynamical systems models. Outcomes from this research have been successfully applied to a wide spectrum of engineering applications. This course will introduce to the students the basic knowledge of the hybrid system modeling framework and the typical methods for their analysis and controller design, to prepare them for a career of control practitioners to deal with the increasingly wider and more challenging control applications nowadays. Current control curriculum at Purdue is no longer adequate for this purpose. Due to the diverse applications of hybrid systems, the course will also be of interest to students from other areas, such as computer engineering, communication and signal processing, etc.

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The course will be jointly listed with AAE, and co-taught with Prof. Inseok Hwang from AAE. A permanent number has been requested and granted for its AAE listing (AAE 668).

Justify the level of the proposed graduate course (500- or 600-level) including statements on, but not limited to: (1) the target audience, including the anticipated number of undergraduate and graduate students who will enroll in the course; and (2) the rigor of the course.

This course will be a 600-level course as it takes as a prerequisite another 600-level course, namely, ECE 602. The target audience will be graduate students who have a working knowledge of the state-space based approach to linear system theory. The students will be asked to conduct a course project on a topic of their choosing but preferably in their own research field. It is unlikely that undergraduate students will be able to meet these requirements.

Use the following criteria:
Graduate Council policy requires that courses at the 50000 level in the Purdue system should be taught at the graduate level and meet four criteria: a) the use of primary literature in conjunction with advanced secondary sources (i.e., advanced textbooks); b) assessments that demonstrate synthesis of concepts and ideas by students; c) demonstrations that topics are current, and; d) components that emphasize research approaches/methods or discovery efforts in the course content area (reading the research, critiquing articles, proposing research, performing research). Such courses should be taught so that undergraduate students are expected to rise to the level of graduate work and be assessed in the same manner as the graduate students.

- Anticipated enrollment
  - Undergraduate 0
  - Graduate 30

B. Learning Outcomes and Method of Evaluation or Assessment:

ECE Graduate Learning Outcomes:

a. Knowledge and Scholarship (thesis/non-thesis)
b. Communication (thesis/non-thesis)
c. Critical Thinking (thesis/non-thesis)
d. Ethical and Responsible Research (thesis) or Professional and Ethical Responsibility (non-thesis)

- List Learning Objectives for this course and map each Learning Objective to one or more of the ECE Learning Outcomes (a-d, listed above):

A student who successfully fulfils the course requirements will have demonstrated

- An understanding of the hybrid system modeling framework
- An ability to analyze the hybrid systems' behaviors
- A knowledge of designing controllers of hybrid systems to meet given design specifications
- An ability to evaluate and verify hybrid systems' performance through numerical simulations
- An ability to apply the knowledge on hybrid systems to a practical problem and present the finding verbally and in a written format to the instructor and peer

students.

- Methods of Instruction

    - Lecturesbased primarily on lecture notes developed by the instructors and occasionally papers in the literature.

- Will/can this course be offered via Distance Learning?

    - The course will not be offered via Distance Learning though it could be if necessary.

- Grading Criteria

Grading criteria (select from checklist); include a statement describing the criteria that will be used to assess students and how the final grade will be determined. Add and delete rows as needed.

    - Homework: a few homework assignments
    - Course projects: team project with at most two students. The projects could be an extension of existing work in the literature or, preferably, involve an original research ideas related to the students' current research.

➤ Describe the criteria that will be used to assess students and how the final grade will be determined:
The course will be graded primarily on a combination of homework and course projects (homework 25%, course project 75%)

C. Prerequisite(s):

List prerequisites and/or experiences/background required. If no prerequisites are indicated, provide an explanation for their absence. Add bullets as needed.

- ECE602 (or AAE564 or equivalent) and MA511 (or equivalent)

- Prerequisite by Topic:

D. Course Instructor(s):

Provide the name, rank, and department/program affiliation of the instructor(s). Is the instructor currently a member of the Graduate Faculty? (If the answer is no, indicate when it is expected that a request will be submitted.) Add rows as needed.

Name	Rank	Dept.	Graduate Faculty or expected date
Jianghai Hu Insoek Hwang	Associate Professor Professor	ECEN AAE	Yes Yes

E. Course Outline:

Provide an outline of topics to be covered and indicate the relative amount of time or emphasis devoted to each topic. If laboratory of field experiences are used to supplement a lecture course, explain the value of the experience(s) to enhance the quality of the course and student learning. For special topics courses, include a sample outline of a course that would be offered under the proposed course. **(This information must be listed and may be copied from syllabus).**

Lectures	Principal Topics
1	Introduction: Motivating examples and outline
3	Background on continuous and discrete time dynamical systems
5	Model of hybrid systems (hybrid automata)
4	Some scientific and engineering applications
5	Reachablity analysis of hybrid systems
5	Stability of hybrid systems
2	Software tools for the simulation of hybrid systems
6	Optimal control of hybrid systems
6	Estimation and identification of hybrid systems
3	Controller synthesis
1	Advanced topics: a geometric theory of hybrid systems
2	Advanced topics: stochastic hybrid systems (SHSs)
1	Advanced topics: game theory

F. Reading List (including course text):

A primary reading list or bibliography should be limited to material the students will be required to read in order to successfully complete the course. It should not be a compilation of general reference material.

A secondary reading list or bibliography should include material students may use as background information.

- Primary Reading List
- Secondary Reading List
    - A book draft currently in preparation by John Lygeros, Claire Tomlin and Shankar Sastry; and selected readings from the literature.

G. Library Resources

Describe any library resources that are currently available or the resources needed to support this proposed course.

H. Course Syllabus

(While not a necessary component of this supporting document, an example of a course syllabus is available, for information, by clicking on the link below, which goes to the *Graduate School's Policies and Procedures Manual for Administering Graduate Student Program.*
See Appendix K.
http://www.purdue.edu/gradschool/faculty/documents/Graduate_School_Policies_and_Procedures_Manual.pdf