Office of the Registrar
FORM 40G REV. 4/10

PURDUE UNIVERSITY

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

Print Form

EFD 9-09

Graduate Council Doc. No. 10-22c

DEPARTMENT School of Aeronautics and Astroanutics

EFFECTIVE SESSION Fall 2011

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/restrictions
- [ ] 11. Change in semesters offered
- [ ] 12. Transfer from one department to another

PROPOSED:		EXISTING:	
Subject Abbreviation	AAE	Subject Abbreviation	
Course Number	66800	Course Number	
Long Title	Hybrid Systems: Theory and Analysis		
Short Title	Hybrid Systems: Theory + Anlys		

Abbreviated title will be entered by the Office of the Registrar if omitted. (30 CHARACTERS ONLY)

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

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

CREDIT TYPE
1. Fixed Credit: Cr. Hrs. 3
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. Special Fees [ ]
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	15	
Recitation				
Presentation				
Laboratory				
Lab Prep				
Studio				
Distance				
Clinic				
Experiential				
Research				
Ind. Study				
Pract/Obsery				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS):

Professor Hwang.

Prerequisite: AAE56400 (or equivalent)
Hybrid systems are dynamical systems with both continuous and discrete dynamics and they are finding increasing applications in a variety of engineering fields, even in scientific fields such as biological systems. This course will present the recent advances in modeling, analysis, control, and verification of hybrid systems. Topics covered in this course include the following aspects of hybrid systems: continuous-time and discrete-event models; reachability analysis; safety specifications and model checking; optimal control and estimation of hybrid systems; stability analysis and verification tools; stochastic hybrid systems; numerical simulations; and a range of engineering applications.

Calumet Department Head	Date	Calumet School Dean	Date	Calumet Undergrad Curriculum Committee	Date
Fort Wayne Department Head	Date	Fort Wayne School Dean	Date	Fort Wayne Chancellor	Date
Indianapolis Department Head	Date	Indianapolis School Dean	Date	Undergrad Curriculum Committee R. Cipra	7/9/2010 Date
North Central Faculty Senate Chair	Date	Vice Chancellor for Academic Affairs	Date	Date Approved by Graduate Council APPROVED 11/18/10	
West Lafayette Department Head	4/29/10 Date	West Lafayette College/School Dean	5/24/2010 Date	Graduate Council Secretary	11/18/10 Date
Graduate Area Committee Convener T. A. Wenstrom	11/18/10 Date	Graduate Dean	Date	West Lafayette Registrar	12/2/10 Date

OFFICE OF THE REGISTRAR

12/2/10

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PROPOSED:	EXISTING:
Subject Abbreviation AAE	Subject Abbreviation
Course Number 66800	Course Number
Long Title Hybrid Systems: Theory and Analysis	
Short Title Hybrid Syst.: Theory & Anal.	

Abbreviated title will be entered by the Office of the Registrar if omitted. (30 CHARACTERS ONLY)

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

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2. Satisfactory/Unsatisfactory Only [ ]
3. Repeatable [ ]
Maximum Repeatable Credit: [ ]
4. Credit by Examination [X]
5. Special Fees [ ]
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Department [ ] Instructor [ ]
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9. Full Time Privilege [ ]
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Lab Prep				
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Distance				
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Experiential				
Research				
Ind. Study				
Pract/Obsery				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS):

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Graduate Area Committee Convener	Date	Graduate Dean	Date	West Lafayette Registrar	Date

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PROPOSED:	EXISTING:
Subject Abbreviation AAE	Subject Abbreviation
Course Number 66800	Course Number
Long Title Hybrid Systems: Theory and Analysis	
Short Title Hybrid Syst.: Theory & Anal.	

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COURSE ATTRIBUTES: Check All That Apply

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Maximum Repeatable Credit: [ ]
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Research				
Ind. Study				
Pract/Observ				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS):

Prerequisite: AAE56400 (or equivalent)
Hybrid systems are dynamical systems with both continuous and discrete dynamics and they are finding increasing applications in a variety of engineering fields, even in scientific fields such as biological systems. This course will present the recent advances in modeling, analysis, control, and verification of hybrid systems. Topics covered in this course include the following aspects of hybrid systems: continuous-time and discrete-event models; reachability analysis; safety specifications and model checking; optimal control and estimation of hybrid systems; stability analysis and verification tools; stochastic hybrid systems; numerical simulations; and a range of engineering applications.

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West Lafayette Department Head	8/13/10 Date	West Lafayette College/School Dean	Date	Graduate Council Secretary	Date
aduate Area Committee Convener	Date	Graduate Dean	Date	West Lafayette Registrar	Date

OFFICE OF THE REGISTRAR

Engineering Faculty Document No.: 9-09
August 12, 2009

TO: Faculty of College of Engineering
FROM: Faculty of the School of Aeronautics and Astronautics
RE: New Graduate Course, AAE 66800 Hybrid Systems: Theory and Analysis

The Faculty of the School of Aeronautics and Astronautics has approved the new course listed below. This action is now submitted to the Engineering Faculty with a recommendation for approval.

AAE 66800 Hybrid Systems: Theory and Analysis
Term offered: Fall (every two years), Lecture 3, Cr. 3.

Prerequisite: AAE56400 (or equivalent)

Course Description:
Hybrid systems are dynamical systems with both continuous and discrete dynamics and they are finding increasing applications in a variety of engineering fields, even in scientific fields such as biological systems. This course will present the recent advances in modeling, analysis, control, and verification of hybrid systems. Topics covered in this course include the following aspects of hybrid systems: continuous-time and discrete-event models; reachability analysis; safety specifications and model checking; optimal control and estimation of hybrid systems; stability analysis and verification tools; stochastic hybrid systems; numerical simulations; and a range of engineering applications.

Reason:
This course introduces students to the basic concepts and theory of hybrid systems, their analysis and numerical simulation tools, and the current state of art of hybrid systems research frontier. This course has been taught as AAE690B (or ECE695) for two terms in Spring 06 and 08 with the enrollments of 10 and 26, respectively. The enrollment has come from various engineering schools including AAE, ECE, ME, and CE. This course is the first course ever co-listed by AAE and ECE at Purdue, which shows that this course would help enhance interdepartmental collaborations in the College of Engineering and Purdue's multidisciplinary efforts and complement the graduate curricula in AAE as well as in the College of Engineering.

Kathleen C. Howell

Kathleen C. Howell, Interim Head
Hsu Lo Professor of Aeronautical and Astronautical Engineering
School of Aeronautics and Astronautics

APPROVED FOR THE FACULTY
OF THE SCHOOLS OF ENGINEERING
BY THE ENGINEERING
CURRICULUM COMMITTEE
ECC Minutes #26
Date 7/9/2010
Chairman ECC R. Cipra

AAE 66800 Hybrid Systems: Theory and Analysis

- **Level:** Graduate

- **Course Instructor:** Inseok Hwang

- **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. Important applications of hybrid systems include CAD, real-time software, robotics and automation, mechatronics, aeronautics, air and ground transportation systems, process control, as well as biological systems. Recently, hybrid systems have been at the center of intense research activity in the control theory, computer-aided verification, and artificial intelligence communities and methodologies have been developed to model hybrid systems, to analyze their behaviors, and to synthesize controllers that guarantee closed-loop safety and performance specifications. These advances have also been complemented by computational tools for the automatic verification and simulation of hybrid systems. This course will cover various aspects of hybrid systems, including their modeling, reachability and stability analysis, controller synthesis, optimization, and simulation tools, that are important in applying hybrid systems to engineering problems.

- **Course outline:**

Topics	**Weeks**
Introduction and Background	1
Motivating examples and outline	
Discrete dynamical systems	
Automata and transition systems	
Continuous dynamical systems	
Ordinary Differential Equations (ODEs): controlled vector fields	
Existence and uniqueness of solutions to ODEs	
Model of hybrid systems (hybrid automata)	2
Definition and well posedness	
Zeno phenomenon	
Composition of hybrid systems with inputs and outputs	
Special classes of hybrid systems: timed automata, switched linear systems	

Applications Safety verification applications (such as transportation systems) Other engineering applications (flight control systems, robotics, etc.) Biological systems	1
Reachability analysis of hybrid systems Reachability problem and its implications in safety verification applications Time evolution of reachable sets for hybrid systems Bisimulation Numerical computation of reachable sets	2
Stability of hybrid systems Lyapunov methods for continuous dynamical systems LaSalle's Principle Lyapunov methods for hybrid systems: piecewise Lyapunov functions Numerical methods for checking the stability of hybrid systems	2
Optimal control of hybrid systems Maximum Principle and classical optimal control theory Dynamic programming of continuous dynamical systems Optimal control of hybrid systems Maximum principle and dynamic programming Geometric theory	3
Estimation of hybrid systems Kalman Filter and classical optimal estimation theory Markov chains Multiple model estimation Hybrid estimators	3
Advanced topics:	1
	Total: 15 weeks

Text: None. Lecture notes/slides and articles from the literature are made available to students.

Grading: Homework 25%; Class Project: 75%

Supporting Document for a New Graduate Course

To: Purdue University Graduate Council

From:
Faculty Member: Inseok Hwang
Department: School of Aeronautics & Astronautics
Campus: West Lafayette, IN

Date: 8/12/2009

Subject: Proposal for New Graduate Course-Documentation Required by the Graduate Council to Accompany Registrar's Form 40G

For Reviewer's comments only (Select One)

Reviewer:

Comments:

Contact for information if questions arise:
Name: Terri Moore
Phone Number: 43006
E-mail: terri@purdue.edu
Campus Address: ARMS 3315

Course Subject Abbreviation and Number: AAE 66800

Course Title: Hybrid Systems: Theory and Analysis

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 fields of study and/or areas of specialization, and how the course relates to other graduate courses offered by the department, other departments, or interdisciplinary programs.

- Justify the level of the proposed graduate course (50000- or 60000-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.

B. Learning Outcomes and Method of Evaluation or Assessment:

- Describe the course objectives and student learning outcomes that address the objectives (i.e., knowledge, communication, critical thinking, ethical research, etc.).

- Describe the methods of evaluation or assessment of student learning outcomes. (Include evidence for both direct and indirect methods.)

- Grading criteria (select from dropdown box); include a statement describing the criteria that will be used to assess students and how the final grade will be determined.

Criteria Papers and Projects

- Identify the method(s) of instruction (select from dropdown box) and describe how the methods promote the likely success of the desired student learning outcomes.

Method of Instruction Lecture

C. **Prerequisite(s):**

- List prerequisite courses by subject abbreviation, number, and title.
- List other prerequisites and/or experiences/background required. If no prerequisites are indicated, provide an explanation for their absence.

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? X Yes — No
  (If the answer is no, indicate when it is expected that a request will be submitted.)

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 or 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.

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.

G. **Library Resources**

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

H. **Example of a 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 Programs*. See Appendix K.)

http://www.gradschool.purdue.edu/downloads/Graduate_School_Policies_and_Procedures_Manual.pdf

AAE 66800 Hybrid Systems: Theory and Analysis

A. Justification for the Course:

The revolution in digital technology has fueled a need for design techniques for complex networked embedded systems (systems-of-systems) that can incorporate both the analog and digital worlds as well as the interconnections and communications between them. Modern engineering problems and solutions feature a mixture of continuous and discrete behaviors. Traditional control courses use tools from calculus and continuous mathematics while computer science works with finite automata and logic. But most real problems require a mixture of both; for example, the design of an autopilot requires careful attention to both discrete logic (flight mode) and continuous differential equations which describe the dynamic behavior of an aircraft in a flight mode. The hybrid systems course is a unique class at Purdue which covers analysis and synthesis of both physical behaviors and discrete logic of embedded systems and thus complements not only the control courses offered in AAE and the College of Engineering (CoE) but also multidisciplinary efforts and activities in the CoE's signature areas such as system-of-systems. This course will present the recent advances in modeling, analysis, control, and verification of hybrid systems. It also emphasizes the need to formulate a problem, plan to solve it, defend the choices made and then present the results to a large audience. Increasingly, engineers are called upon to work in teams on large and complex projects: the training for such careers needs to be provided as part of the student's education and this course will help prepare students their career in this area.

The level of the proposed course is at the 60000-level because the target audience is Masters and PhD graduate students in both Engineering and Non-Engineering who satisfy the course requirement which is a 50000-level course. The anticipated number of students who will enroll in the course is approximately 20. The course requires students of high intellectual rigor who can understand fundamentals in science and engineering and apply knowledge to various applications.

B. Learning Outcomes and Method for Evaluation or Assessment:

The objective of this course is to study the basic concepts and theory of hybrid systems; to acquaint the students with their analysis and numerical simulation tools; to familiarize the students with the current state of art of hybrid systems research frontier; and to encourage the students to apply the hybrid systems model to problems in their own fields of study and other multidisciplinary areas.

The evaluation of the course is based on the class projects, presentations, and homework.

The method of instruction is mainly based on lectures. In addition, students are required to set up their own class projects, mathematically formulate a problem, solve the problem, and present the result to the class in two ways: oral presentation and report. The proposed methods would promote likely success of the desired student learning outcomes such as knowledge, communication and critical thinking because they focus on building knowledge on hybrid systems and skills in solving various application problems and presenting results in an effective way.

C. Prerequisite(s)

The prerequisite for this course is AAE 56400 (Linear Systems Analysis and Synthesis) or equivalent.

D. Course Instructor:

Dr. Inseok Hwang, Assistant Professor, School of Aeronautics and Astronautics

The instructor is currently the Graduate Faculty.

E. Course Outline:

Topics	**Lectures**
Introduction Motivating examples and outline	1
Background Discrete dynamical systems Automata and transition systems Continuous dynamical systems Ordinary Differential Equations (ODEs): controlled vector fields Existence and uniqueness of solutions to ODEs	3
Model of hybrid systems (hybrid automata) Definition and well posedness Zeno phenomenon Composition of hybrid systems with inputs and outputs Special classes of hybrid systems: timed automata, switched linear systems	6
Applications Safety verification applications (such as transportation systems) Other engineering applications (flight control systems, robotics, etc.) Biological systems	3
Reachability analysis of hybrid systems Reachability problem and its implications in safety verification applications Time evolution of reachable sets for hybrid systems Bisimulation Numerical computation of reachable sets	6
Stability of hybrid systems Lyapunov methods for continuous dynamical systems LaSalle's Principle Lyapunov methods for hybrid systems: piecewise Lyapunov functions Numerical methods for checking the stability of hybrid systems	6

Optimal control of hybrid systems 9

- Maximum Principle and classical optimal control theory
- Dynamic programming of continuous dynamical systems
- Optimal control of hybrid systems
- Maximum principle and dynamic programming
- Geometric theory

Estimation of hybrid systems 9

- Kalman Filter and classical optimal estimation theory
- Markov chains
- Multiple model estimation
- Hybrid estimators

Advanced topics: 2

Total: 45

F. Reading List (including course text):

- Lecture notes and papers/articles on the related topics

G. Library Resources

- Reading material s are available on Blackboard Vista

PURDUE
UNIVERSITY

GRADUATE SCHOOL
Office of the Dean

To: School of Aeronautics – Linda Higgins

From: The Graduate Programs Office

Date: July 27, 2010

Subject: The Form 40G is being returned for the following information:

- ☐ Course Description is blank
- ☐ Prerequisite may be added in the Course Description

Please return to: Debbie Fellure/Graduate School, Room 160/YONG

Debra Fellure
765-494-6963
dfellure@purdue.edu

Corrected
file