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Office of the Registrar
FORM 40G REV. 11/09

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

Print Form

EFD 8-09

Graduate Council Doc. No. 10-22b

DEPARTMENT School of Aeronautics and Astronautics   EFFECTIVE SESSION Spring 2011

STRUCTIONS: 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 AAE
Course Number 56800
Long Title Applied Optimal Control and Estimation
Short Title ~~Applied Opt. Ctrl. & Estimat.~~ Appl Optimal Cntrl + Estimation
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:
[ ] Summer [ ] Fall [X] Spring

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

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/Observ				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS):
Prerequisite: AAE 56400 (or equivalent).
This course introduces students to analysis and synthesis methods of optimal controllers and estimators for (stochastic) dynamical systems. The topics in this course include a review of probability and stochastic processes, classical estimation techniques, Pontryagin's maximum principle, dynamic programming, Linear Quadratic Regulator problems (LQR), Kalman filter, duality of LQR with Kalman filter, Linear Quadratic Gaussian (LQG), and a range of engineering applications.
Professor Hwang.

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	[signature] 2/16/2010 Undergrad Curriculum Committee — Date
North Central School Dean — Date	North Central Vice Chancellor for Academic Affairs — Date	APPROVED 10/21/10 Date Approved by Graduate Council
[signature] 3/28/10 West Lafayette Department Head — Date	[signature] 2/22/2010 West Lafayette College/School Dean — Date	[signature] 10/25/10 Graduate Council Secretary — Date
[signature] 10/21/10 Graduate Area Committee Convener — Date	Graduate Dean — Date	[signature] 11/5/10 West Lafayette Registrar — Date

OFFICE OF THE REGISTRAR

11/23/10 dt 11-24-10

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Course Number 56800
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Short Title Applied Opt. Ctrl. & Estimat.

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Subject Abbreviation
Course Number

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Minimum Cr. Hrs
(Check One) To [ ] Or [ ]
Maximum Cr. Hrs.
3. Equivalent Credit: Yes [ ] No [ ]
4. Thesis Credit: Yes [ ] No [ ]

COURSE ATTRIBUTES: Check All That Apply
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3. Repeatable [ ]
Maximum Repeatable Credit: [ ]
4. Credit by Examination [ ]
5. Special Fees [ ]
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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	R. Cipra 2/16/2010 Undergrad Curriculum Committee Date
North Central School Dean Date	North Central Vice Chancellor for Academic Affairs Date	Date Approved by Graduate Council
[signature] 3/28/10 West Lafayette Department Head Date	[signature] 2/22/2010 West Lafayette College/School Dean Date	Graduate Council Secretary Date
Graduate Area Committee Convener Date	Graduate Dean Date	West Lafayette Registrar Date

OFFICE OF THE REGISTRAR

Engineering Faculty Document No.: 8-09
September 25, 2008

TO: Faculty of College of Engineering
FROM: Faculty of the School of Aeronautics and Astronautics
SUBJECT: New Graduate Course, AAE 56800 Applied Optimal Control and Estimation

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 56800 Applied Optimal Control and Estimation
Sem. 2 (every two years), Class 3, cr. 3.

Prerequisite: AAE56400 (or equivalent)

Course Description:
This course introduces students to analysis and synthesis methods of optimal controllers and estimators for (stochastic) dynamical systems. The topics in this course include a review of probability and stochastic processes, classical estimation techniques, Pontryagin's maximum principle, dynamic programming, Linear Quadratic Regulator problems (LQR), Kalman filter, duality of LQR with Kalman filter, Linear Quadratic Gaussian (LQG), and a range of engineering applications.

Reason:
Optimal control and estimation have been widely used in various applications including a wide range of engineering problems as well as non-engineering problems in areas such as biology, management, and social science, and is one of the fundamental courses for systems theory. However, no similar class that integrates all of these topics has been offered at Purdue for several years. This course could help students build their knowledge on optimal control and estimation and would complement the graduate curricula in AAE as well as in the College of Engineering. This course has been taught as AAE590W in Spring 07 with the enrollment of 21. The enrollment has come from various engineering schools including AAE, ECE, ME, and CE as well as outside of engineering such as psychology.

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 #10
Date 12/7/09
Chairman ECC R Cipra

AAE 568 Applied Optimal Control and Estimation

- **Level:** Graduate and Undergraduate
- **Course Instructor:** Inseok Hwang
- **Course Description:**

The main objective of this course is to study analysis and synthesis methods of optimal controllers and estimators for (stochastic) dynamical systems. Optimal control is a time-domain method that computes the control input to a dynamical system which minimizes a cost function. The dual problem is optimal estimation which computes the estimated states of the system with stochastic disturbances by minimizing the errors between the true states and the estimated states. Combination of the two leads to optimal stochastic control. Applications of optimal stochastic control are to be found in various areas in science, economics, and engineering. The course presents a review of probability and random processes, calculus of variations, dynamic programming, Maximum Principle, optimal control and estimation, duality, and optimal stochastic control.

- **Course outline:**

Topics	**Weeks**
Introduction and review of some mathematical background	2
Linear systems:	
Controllability and Observability	
Pole placement and observer design	
Probability and stochastic processes	
Classical estimation	2
Minimum variance unbiased estimation	
Least squares estimation	
Maximum likelihood estimation	
Optimal control	5
Calculus of variations: Two-point boundary value problem	
Maximum/Minimum principle	
Hamilton-Jacobi-Bellman equation	
Dynamic Programming	
Linear Quadratic (LQR) problems	
Finite-time and infinite-time horizon LQR	
Continuous-time and discrete-time LQR	
Gauss-Newton LQR	
Receding horizon LQR	

	Weeks
Optimal estimation	4
Stochastic dynamic systems	
Discrete-time/Continuous-time stochastic linear systems	
Controllability and stability	
Stochastic dynamic programming	
Kalman Filter	
Discrete-time and continuous-time Kalman filters	
Hybrid Kalman filter: continuous dynamics and discrete measurement	
Extended Kalman filters	
Duality of LQR with Kalman filter (LQE)	2
Stochastic optimal control	
Separation principle	
Linear Quadratic Gaussian (LQG)	
	Total: 15 weeks

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

Grading: Homework 25%; Exam: 25%; Class Project: 50%

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:	11/16/2009	
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: Armstrong Hall Rm #3315

Course Subject Abbreviation and Number: AAE 56800

Course Title: Applied Optimal Control and Estimation

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 Exams and Quizzes

- 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 [ ]

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? __ 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 568 Applied Optimal Control and Estimation

A. Justification for the Course:

Optimal control and estimation have been widely used in various applications including a wide range of engineering problems as well as non-engineering problems in areas such as biology, management, and social science, and is one of the fundamental courses for systems theory. However, no similar class has been offered at Purdue for several years. This course could help students build their knowledge on optimal control and estimation and would complement the graduate curricula in AAE as well as in the College of Engineering.

The main objective of this course is to study analysis and synthesis methods of optimal controllers and estimators for (stochastic) dynamical systems. The course presents fundamentals of probability and random processes and detailed knowledge in optimization and optimal control/estimation of stochastic dynamical 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 50000-level because the target audience is senior-level undergraduates and graduate students in both Engineering and Non-Engineering who satisfy the course requirement. 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 Methodof Evaluation or Assessment:

The objective of this course is to study analysis and synthesis methods of optimal controllers and estimators for stochastic dynamical systems. The course presents a review of probability and random processes, calculus of variations, dynamic programming, Maximum Principle, optimal control and estimation, duality, and optimal stochastic control. Through class projects, students learn how to effectively communicate their ideas and how to formulate a problem and solve it.

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 optimal control and estimation and skills in solving various application problems and presenting results in an effective way.

C. Prerequisite(s)

The prerequisite for this course is AAE 564 (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	1
Review of some mathematical background	6
Linear systems:	(2)
Controllability and Observability	
Pole placement and observer design	
Probability and stochastic processes	(4)
Classical estimation	6
Minimum variance unbiased estimation	(2)
Least squares estimation	(2)
Maximum likelihood estimation	(2)
Optimal control	15
Calculus of variations: Two-point boundary value problem	(2)
Maximum/Minimum principle	(2)
Hamilton-Jacobi-Bellman equation	(2)
Dynamic Programming	(3)
Linear Quadratic (LQR) problems	(6)
Finite-time and infinite-time horizon LQR	
Continuous-time and discrete-time LQR	

Gauss-Newton LQR

Receding horizon LQR

Optimal estimation	12
Stochastic dynamic systems	(2)
Discrete-time/Continuous-time stochastic linear systems	
Controllability and stability	
Stochastic dynamic programming	(2)
Kalman Filter	(7)
Discrete-time and continuous-time Kalman filters	
Hybrid Kalman filter: continuous dynamics and discrete measurement	
Extended Kalman filters	
Duality of LQR with Kalman filter (LQE)	(1)
Stochastic optimal control	5
Separation principle	
Linear Quadratic Gaussian (LQG)	

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