FLORIDA ATLANTIC UNIVERSITY™

Graduate Programs—NEW COURSE PROPOSAL[1]

UGPC APPROVAL _____
UFS APPROVAL _____
SCNS SUBMITTAL _____
CONFIRMED _____
BANNER POSTED _____
CATALOG _____

DEPARTMENT: COMPUTER & ELECTRICAL ENGINEERING & COMPUTER SCIENCE

COLLEGE: ENGINEERING AND COMPUTER SCIENCE

RECOMMENDED COURSE IDENTIFICATION:
PREFIX __EEL_____ COURSE NUMBER __6620_____ LAB CODE (L or C) _____
(TO OBTAIN A COURSE NUMBER, CONTACT MJENNING@FAU.EDU)

COMPLETE COURSE TITLE: NONLINEAR CONTROL SYSTEMS ENGINEERING

EFFECTIVE DATE
(first term course will be offered)
SPRING 2015

CREDITS[2]: 3

TEXTBOOK INFORMATION: "Applied Nonlinear Control" by Jean-Jacques E. Slotine & Weiping Li, Prentice Hall 1991.

GRADING (SELECT ONLY ONE GRADING OPTION): REGULAR __X___ SATISFACTORY/UNSATISFACTORY _____

COURSE DESCRIPTION, NO MORE THAN THREE LINES: This course explores the most common nonlinearities that occur in practical feedback control design and their effect on system's performance and control design. Course covers Phase Plane Methods, Describing Function, PID auto-tuning, Sliding Mode Control, Lyapunov Control Design and Feedback Linearization.

PREREQUISITES *: EEL 4652 CONTROL SYSTEMS 1	COREQUISITES*: N/A	REGISTRATION CONTROLS (MAJOR, COLLEGE, LEVEL)*: 6XXX LEVEL – GRADUATE STANDING

* PREREQUISITES, COREQUISITES AND REGISTRATION CONTROLS WILL BE ENFORCED FOR ALL COURSE SECTIONS.

MINIMUM QUALIFICATIONS NEEDED TO TEACH THIS COURSE: PHD

Faculty contact, email and complete phone number:	Please consult and list departments that might be affected by the new course and attach comments.[3]
Dr. Zvi Roth, rothz@fau.edu, 7-3471	**Mathematics, Brain Science & Complex systems, Ocean and Mechanical Engineering**

Approved by:	*Date:*
Department Chair: Nancy Gerhart	11/27/13
College Curriculum Chair: Wei Tech	11/27/13
College Dean:	12/2/2013
UGPC Chair:	1/22/14
Graduate College Dean:	1-29-14
UFS President:	
Provost:	

1. **Syllabus** must be attached; see guidelines for requirements: *www.fau.edu/provost/files/course syllabus.2011.pdf*
2. Review **Provost Memorandum: Definition of a Credit Hour** *www.fau.edu/provost/files/Definition_Credit_Hour_Memo_2012.pdf*
3. **Consent** from affected departments (attach if necessary)

Email this form and syllabus to *UGPC@fau.edu* **one week before** the University Graduate Programs Committee meeting so that materials may be viewed on the UGPC website prior to the meeting.

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EEL ~~6xxx~~ - Nonlinear Control Systems Engineering

3 credits

Course Syllabus

Instructor: Dr. Zvi S. Roth

Phone: (561)-297-3471

Fax: (561)-297-2800

e-mail: rothz@fau.edu

Prerequisites: EEL 4652 Control Systems 1 (or an equivalent course)

Prerequisites by topic: a) Classical control theory: Transfer functions, poles, zeros, stability of linear systems, steady-state error, control design using Bode plots and Root Locus, b) Basics of Matlab and Simulink for dynamic system simulations

Co-requisites: N/A

Typical Course Delivery Format: Live class in a TV studio and distance learning sections

Textbook: **"Applied Nonlinear Control" by Jean-Jacques E. Slotine & Weiping Li, Prentice Hall 1991,** or an equivalent (more recent) book that may cover the subjects listed below.

** Compared to many recent Nonlinear Systems textbooks the book by Slotine and Li is unique in two ways: a) It covers both the theoretical Lyapunov-type material along with engineering-oriented topics such as Sliding Mode control. It is a unique combination of topics, b) The book is decidedly Engineering rather than Applied Mathematics that most other books are.
The book is also available in paper cover.

Required Software: Any recent edition of Matlab Student Edition (which comes with Simulink). Students may use the software available on the FAU College of Engineering and Computer Science servers.

Course Description and Objectives: This course is one of several possible second courses in Control Systems. It explores the most common nonlinearities that occur in practical feedback control design (friction, backlash, saturation etc.) and their effect on system's performance and control design. Many practical control design methods (such as PID auto-tuning) are based on nonlinear systems concepts.

Other popular and very powerful design techniques (such as Sliding Mode Control, or Lyapunov Design) are intentionally nonlinear.

The course will rarely stray from the single-input/single-output/single-feedback-loop set-up, even though extensions to more general cases will be shown from time to time.

The following are some of the course's concepts and specific skills that a student is expected to master (more or less…) after completing the course:

1) Recognition and simulation of system nonlinearities and their effect on the system dynamic behavior.
2) Understanding of the process of linearization and its range of validity.
3) Understanding of the concept of stability, the causes for instability and the means to stabilize a system.
4) Understanding of the concept of feedback.
5) The carrying out of a control design for single-input single-output linear and nonlinear time-invariant feedback systems, using a variety of nonlinear control design tools.
6) Simulation, analysis and design of systems, using MATLAB, MATLAB SIMULINK and MATLAB CONTROL TOOLBOX.

Grading Policy:

Midterm Exam	35%
Final Exam	35%
Simulation Projects (6 projects, each counts for 5%)	30%

Conversion from 0-100 scale to a letter grade will be done using the following linear scale:

A= 90-100%, A-=85-89%, B+=80-84%, B=75-79%, B-=70-74%, C+=65-69%, C=60-64%, C-=55-59%, D+=50-54%, D=45-49%, D-=40-44%, F=0-39%.

There will be no grade-curving of any sort. All final grades that fall within 1% of a grade threshold will be reviewed. Special consideration to overcome a 1% grade deficit will be extended only to students who demonstrated consistent hard work throughout the semester (as evidenced from the MATLAB projects).

Homework Format:

Each simulation solution must be submitted via e-mail and also by a printout stapled at the upper left corner. Homework must be typed. No scanned handwritten notes are allowed. It should be neatly edited and should include the following items:

1) Some hand calculations (in case of a design exercise) predicting approximately the expected outcome. In the case of a design activity explain your design considerations.
2) Printout of the MATLAB code and/or the SIMULINK block diagram. Put annotations to fully describe inner-block's parameters or the simulation parameters. Also include comments regarding the ideas behind a certain block diagram.
3) Output printouts – Be selective and use only the most relevant output. Don't dump on me your entire collection of computer printouts. In particular, never submit graphs that you cannot explain.
4) Annotations to the results: It is best to put comments and annotations directly on all output graphs and system diagrams. It is highly recommended (for best readability of your work) to include notes and computations directly on the output graph pages themselves.
5) Brief conclusions – Did the system work as expected? If the results are far from your hand-calculation prediction, where is the difference coming from?

Cheating Policy:

It's ok to consult with friends. It's not ok to merely add your name to a program obtained from a friend. "File Sharing" or "Group Projects" (other than the allowed team presentation projects) is unethical. Each submitted work must be highly individual in terms of editing style, comments and conclusions. The 1% letter grade deficit policy is a privilege. It will be promptly and permanently revoked for anybody caught in any unethical conduct. Cheating may sometimes lead to a more drastic grade consequences.

FAU Code of Academic Integrity Policy: *Students at Florida Atlantic University are expected to maintain the highest ethical standards. Academic dishonesty is considered a serious breach of these ethical standards, because it interferes with the university mission to provide a high quality education in which no student enjoys an unfair advantage over any other. Academic dishonesty is also destructive of the university community, which is grounded in a system of mutual trust and places high value on personal integrity and individual responsibility. Harsh penalties are associated with academic dishonesty. For*

more information, see University Regulation 4.001. URL TO be added.

FAU Disability Policy: In compliance with the Americans with Disabilities Act (ADA), students who require reasonable accommodations due to a disability to properly execute coursework must register with the Office for Students with Disabilities (OSD) in Boca Raton, SU 133 (561-297-3880); in Davie, LA240 (954-236-1222); in Jupiter, SR 11(561799-8010); or at the Treasure Coast, CO 117(772-873-3441) – and follow all OSD procedures. URL TO be added.

Policy on Make-up Tests, Late Submissions and Incomplete Grades:

1) The course is expected to always have Distance Learning (DL) sections. Students who register in one of the DL sections are expected to coordinate their exam time, and proctoring arrangements, with the College of Engineering Office of Distance Education. DL exams will typically be similar to the regular exams, and will just be administered one day later.
2) Students who are registered to the live section and need a make-up exam, due to health reasons or family hardship, can too benefit from the services of the COECS Distance Education Office
3) Homework projects have deadlines as specified in the Course Calendar. Being late by a few days is typically forgiven. Longer late submission periods may result in grade penalties or complete loss of points, depending how late the submission is.
4) Incomplete grades will be given only to students who experience health problems or family hardship problems. Written evidence is expected.

Final Advice:

1) **Keep open channels of communication with the course instructor - e-mail, call on the phone or visit during office hours.**
2) **Never allow yourself to "get stuck" on a homework problem - seek help. You may do it by e-mailing the professor and make sure to include jpg or pdf versions of your SIMULINK models or MATLAB m. file program as attachments. Answers will come as soon as possible. In addition the questions and answers will be added into a Q & A announcements posted in Blackboard. Your questions therefore benefit the entire class.**

3) **Whenever you feel "stuck" reading the theory or doing the hands-on assignments, try to articulate in words what exactly it is that you don't understand. Then e-mail your questions.**
4) **Office Hour help is most productive, if you take the effort, ahead of the meeting, to do some preliminary work, and have some specific questions.**
5) **Always keep a "cool head" during the exams. Exam questions will never be tricky. They are designed only to assess your knowledge in a straightforward manner, and reward you if you did all the homework assignments properly.**
6) **When preparing for an exam, don't skip topics. Exams attempt to cover ALL topics. Every one of the problems may feature a mix of several topics.**
7) **Exams are closed books and closed notes. One 8.5 by 11 sheet of formulas is allowed (page can be double sided).**
8) **Bring simple scientific calculator to the exams.**

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EEL ~~6xxx~~ Nonlinear Control Systems Engineering
Typical 15 week semester Course Calendar

Week/ Lecture	Topic	Homework Deadlines / Comments
I/1	Course Introduction & Syllabus; Linear vs. Nonlinear Systems & Characteristics	
I/2	The Phase Plane: 2nd Order Linear System's Trajectories and Equilibrium Point Classification – Node, Focus, Center, Saddle	HW1 given (Phase Plane)
II/3	Matlab Simulink Tutorial (demonstrating linear second order systems): Model Construction, Transfer of Results from Simulink to Matlab, Running a Simulink model from Matlab	
II/4	Example: The Logistic Model and its Linearization; The Phase Plane: 2nd Order Nonlinear System examples – Finding equilibrium Points	
III/5	Linearization: Lyapunov's First Theorem; Examples (including Predator-Prey Models, Two-Species Competition Models and Symbiosis Models)	HW2 given (Linearization)
III/6	Matlab/Simulink: Linearization using Trim and Linmod commands applied to model subsystems	HW1 due
IV/7	Conservative Systems; Piecewise Linear Nonlinear Systems – Real and Virtual Equilibrium Points	
IV/8	Phase Plane Analysis of Common Nonlinearities in Position and Velocity Servo Systems: Saturation, Dead Zone, Static Friction, Backlash in Gears	
V/9	Matlab-Simulink Analysis of nonlinearities in Servo Systems; Relay Servomechanisms: Sliding Mode Effects due to velocity feedback; Minimum Time Relay (Bang-Bang)	HW3 given (Nonlinear servo systems)

	Control	
V10	Sliding Mode Control: Single and Multi Relay Implementation; Control Smoothing via replacement of relays with high gain amplifiers	HW2 due
VI/11	Matlab-Simulink demonstration of Sliding Mode Control	
VI/12	PID Control Auto-Tuning with Simulink demonstrations: Classical Tuning due to Ziegler-Nichols, ISE and ISTE measures of tuning quality	
VII/13	Limit Cycle Theorems for 2nd Order systems; Van-der-Pol Oscillator and Introduction to Describing Functions	HW3 due
VII	**Mid-Term Exam**	Covering Phase Plane, Linearization and Nonlinear Servo systems
VIII/14	The Describing Function Method – Nonlinear Elements with Real DF and Servo loop limit cycle analysis and prevention design	HW4 given (Sliding Mode)
VIII/15	Matlab-Simulink demonstration of Discribing Functions; PID Auto-Tuning using Astrom's Relay Method	
IX/16	Describing Function Method (concluded) – Hysteresis Elements with complex DF; DF analysis and design examples Theory and Matlab-Simulink demonstration of the SI PID Auto-Tuning Method	
IX/17	Definitions of Stability; Positive Definite Functions and other mathematical preliminaries to Lyapunov's Second Theorem	HW5 given (PID, Describing Functions)
X/18	Lyapunov's Stability, Asymptotic Stability, Global Asymptotic Stability and Instability Theorems	HW4 due
X/19	LaSalle's extensions to Lyapunov's theorems and applications; Construction Methods of Lyapunov Functions	
XI/20	Lyapunov stability theory examples	
XI/21	Nonlinear Control Design based on Lyapunov Theory	

XII/22	Matlab-Simulink Simulation of a Pendulum on a Cart system and Lyapunov Control Design	
XII/23	Theory and Matlab-Simulink demonstration of Phase-Locked Loops	HW6 given (Lyapunov)
XIII/24	Feedback Linearization Basic Concepts: Controllability canonical Form, Introduction to Input-State Linearization and Input-Output Linearization; Internal Dynamics and Relative Degree	HW5 due
XIII/25	Mathematical Background for Feedback Linearization: Lie Derivative and Lie Bracket, Diffeomorphism, Frobenius Theorem	
XIV/26	Input-State Linearization of SISO systems	
XIV/27	Input-Output Linearization	HW6 due
XV/28	Review of material for the final exam	
XV	**Final Exam**	**Covering Sliding Mode, PID, Describing Function, Lyapunov** Phase Locked Loops and Feedback Linearization – not covered

RE: [Fwd: Course number request]

Lee Klingler
Sent: Monday, November 04, 2013 6:28 AM
To: Zvi Roth
Cc: Yuan Wang; Rainer Steinwandt

Dear Zvi,

The mathematics department has no opposition to your reinstating the course EEL 6624 (Nonlinear Systems), which will emphasize the applications of control theory.

Regards,
Lee

From: Yuan Wang [ywang.fau@gmail.com]
Sent: Sunday, November 03, 2013 10:26 AM
To: Lee Klingler
Subject: [Fwd: Course number request]

Hi Lee,

I hope you had a good time with the marathon.

Yuandan and I have looked at the description of the course. It is fine with both of us for the EE to offer this course. The course pretty much focus on the applied aspects. In case if we offer a course on control theory, it would emphasize the theoretical aspects.

Before I reply to Zvi, let me see if it is fine with you. Are there others in the dept that I should contact?

Best,
Yuan

-------- Original Message --------
Subject: Course number request
Resent-From: <YWANG@fau.edu>
Date: Thu, 31 Oct 2013 20:10:05 +0000
From: Zvi Roth <rothz@fau.edu>
To: Yuan Wang <YWANG@fau.edu>

Hi Yuan,
I am trying to reinstate a course that existed in the catalog till 2006 (it used to be called EEL 6624 Nonlinear Systems) and was then removed by mistake. See attached.
Does the Mathematics Department have any concerns or reservations?
Please share with Yuandan and whoever else is interested in control courses.
Regards,
Zvi

Dr. Zvi S. Roth
Professor
Department of Computer & Electrical Engineering & Computer Science

RE: Course number request

Janet Blanks
Sent: Thursday, October 31, 2013 4:36 PM
To: Zvi Roth

Hi Zvi,

No, go ahead!

Janet

From: Zvi Roth
Sent: Thursday, October 31, 2013 4:12 PM
To: Janet Blanks
Subject: Course number request

Hi Janet,
I am trying to reinstate a course that existed in the catalog till 2006 (it used to be called EEL 6624 Nonlinear Systems) and was then removed by mistake. See attached.
Does the Brain Science and Complex Systems program have any concerns or reservations? Please share with the appropriate individuals.
Regards,
Zvi

Dr. Zvi S. Roth
Professor
Department of Computer & Electrical Engineering & Computer Science
Florida Atlantic University
Engineering East Building, Room 519
777 Glades Road
Boca Raton, FL 33431
561-297-3471

RE: Course number request

Javad Hashemi
Sent: Thursday, October 31, 2013 4:13 PM
To: Zvi Roth

Dear Zvi, we have no objections. Some of our students may take this. You are kind for asking.

When are you offering controls I?

Thanks.

Javad

From: Zvi Roth
Sent: Thursday, October 31, 2013 4:08 PM
To: Javad Hashemi
Subject: Course number request

Hi Javad,
I am trying to reinstate a course that existed in the catalog till 2006 (it used to be called EEL 6624 Nonlinear Systems) and was then removed by mistake. See attached.
Does the OME Department have any concerns or reservations?
Regards,
Zvi

Dr. Zvi S. Roth
Professor
Department of Computer & Electrical Engineering & Computer Science
Florida Atlantic University
Engineering East Building, Room 519
777 Glades Road
Boca Raton, FL 33431
561-297-3471