FAU **FLORIDA ATLANTIC UNIVERSITY**	**COURSE CHANGE REQUEST** **Graduate Programs** **Department** CEECS **College** College of Engineering and Computer Science	UGPC Approval ____ UFS Approval ____ SCNS Submittal ____ Confirmed ____ Banner Posted ____ Catalog ____

Current **Course Prefix and Number** EEL 5613	***Current*** **Course Title** Modern Control

*Syllabus must be attached for **ANY** changes to current course details. See Guidelines. Please consult and list departments that may be affected by the changes; attach documentation.*

Change title to:	**Change description to:**
Change prefix **From:** **To:**	**Change prerequisites/~~minimum grades to~~: From "MAS 5145 or Engineering Graduate Standing" to "Engineering graduate standing or instructor's permission"**
Change course number **From:** **To:**	
Change credits* **From:** **To:**	**Change corequisites to:**
Change grading **From:** **To:** *Review Provost Memorandum	**Change registration controls to:**
Effective Date *(TERM & YEAR)* *Fall 2018*	**Terminate course** **List final active term**

Faculty Contact/Email/Phone **Dr. Zvi Roth / rothz@fau.edu / 7-3471**

Approved by	***Date***
Department Chair Nurgun Erdol	2/13/18
College Curriculum Chair McCandie	2/14/18
College Dean [signature]	2/14/2018
UGPC Chair	
UGC Chair	
Graduate College Dean	
UFS President	
Provost	

Email this form and syllabus to UGPC@fau.edu one week before the UGPC meeting.

GRADUATE COLLEGE
FEB 21 2018
Received

Department of Computer & Electrical Engineering and Computer Science

Florida Atlantic University
Course Syllabus

1. Course title/number, number of credit hours	
Modern Control – EEL 5613 (Call Numbers: 14635 – live; 14636 – DL)	3 credit hours
2. Course prerequisites, corequisites, and where the course fits in the program of study	
Prerequisites: Engineering Graduate Standing or Instructor's Permission	
3. Course logistics	
Term: Fall 2018 This is a classroom lecture course with videos fed to Canvas *Class location and time*: TV Studio (TBA) T Th 3:30-4:50 pm This course has design content. The course, also, qualifies as a possible course to satisfy the Electrical Engineering Graduate Math Requirement.	
4. Instructor contact information	
Instructor's name	Dr. Zvi S. Roth, Professor
Office address	Engineering East (EE-96) Bldg., Room 519
Office Hours	T W Th 11:00-12:00
Contact telephone number	561-297-3471
Email address	rothz@fau.edu
5. TA contact information	
TA's name	N/A
Office address	
Office Hours	
Contact telephone number	
Email address	
6. Course description	
Fundamentals of linear systems theory and practice as applied to multi-input and multi-output feedback control systems: state variable models, stability, controllability, observability, state feedback and estimation, linear quadratic regulators, computer aided analysis and design (using Matlab control systems toolbox) The course is one of several approved EE graduate level courses that satisfy the graduate math requirement for the EE MS/PhD programs. The course may be viewed as one of several possible second courses in Control (a follow-up to Control Systems 1) but it may also be considered as a standalone Advanced Linear Systems course, useful not only for graduate students who pursue research in Control Systems or Robotics, but to students who opt to focus on areas such as Telecommunication or Digital Signal Processing.	
7. Course objectives/student learning outcomes/program outcomes	

Course objectives	1. The student will be able to understand the principles and concepts of modern state variable control (a. e. k). 2. Understand and the mathematical and analytical tools of modern control (a. e. k). 3. Understand and apply simulation techniques for control system design in the state space (a. e. k). The course may be viewed as one of several possible second courses in Control (a follow-up to Control Systems 1) but it may also be considered as a standalone <u>Advanced Linear Systems</u> course, useful not only for graduate students who pursue research in Control Systems or Robotics, but to students who opt to focus on areas such as Telecommunication or Digital Signal Processing. The course is one of a very few graduate level Electrical Engineering courses designated as courses that may **satisfy the graduate mathematics requirement for Electrical Engineering**. It has indeed very rigorous math contents – Linear Algebra and Matrix Theory, combined with Differential Equations, and some elements of Functional Analysis. Almost all theorems are rigorously proved. The course will deal only with finite-dimensional continuous-time systems. The following are some of the course's concepts and specific skills that a student is expected to master after completing the course: The following are some of the course's concepts and specific skills that a student is expected to master after completing the course: 1) Setup and solution of linear time-varying and time-invariant state-variable equations. 2) Understanding the connection between state-variable model and transfer-function matrix, and in particular understanding what Stability is. 3) Understanding the concepts of Controllability and

	Observability, and consequently the concept of Stabilizability. 4) Understanding control design by means of State Feedback. 5) Understanding the design of State Observers 6) Familiarity with Least Squares Control Design for Tracking, Regulation, Minimum Control Effort and other design specifications 7) (if time permits) Understanding how to realize minimally a system model based on observation data.
Student learning outcomes & relationship to ABET a-k objectives	1. The student will demonstrate an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. (k) 2. The student will demonstrate ability to apply knowledge of math, science and engineering. (a) 3. The student will demonstrate the ability to communicate in writing a technical report. (g) 4. The student will demonstrate ability to identify, formulate, and solve engineering problems. (e)
8. Course evaluation method	
Grade There will be 5 homework assignments. Each homework is weighted as 10% of the course total grade.	
There will be a 50 minute "no risk" Midterm Exam (Date TBA). The midterm exam grade (if larger than the final exam grade) will worth 25% of the total course grade. If the final exam grade happens to be larger than the midterm grade, the midterm grade will not be taken into account. Hence, "no risk". The midterm exam can only help and in a very meaningful way, as the final	

exam is much longer and covers much more material.
The final exam is 2 hours and 30 minutes long. It is worth 50% of the total course grade (if the midterm grade is not good) or only 25% in case the midterm grade is good.

9. Course grading scale

Grading 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: 39 and below: "F."

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 are in good standing .

10. Policy on makeup tests, late work, and incompletes

Makeup tests are given only if there is solid evidence of a medical or otherwise serious emergency that prevented the student of participating in the exam. Makeup exam should be administered and proctored by department personnel unless there are other pre-approved arrangements
Late homework submission is allowed and is not penalized if the late period is brief. Lengthy delayed submission may incur points penalties.

Incomplete grades are against the policy of the department. Unless there is solid evidence of medical or otherwise serious emergency situation incomplete grades will not be given.

Homework submission guidelines:

1) All submissions must first be done by e-mail with Word or pdf files submitted by the required deadline, to Dr. Roth's email rothz@fau.edu.
2) In homework assignments that include MATLAB, please add the code to the solution. If some mathematical proof is needed, please include the complete proof.
3) Some of the homework submissions (especially ones that do not have too much scanned contents) may be selected for the course Gallery of Best Solutions. Each homework that is so selected will earn a 1% grade bonus.

11. Special course requirements

Exams: Open books and notes. The use of electronic devices such as laptops and iPads is allowed. Each test covers roughly one half of the course's material. The course's Blackboard web site contains large number of prior semesters' tests (blank forms for self practice and full solutions). Exam problems will be similar to old exam problems.

12. Classroom etiquette policy

Attendance is not mandatory (except for the two exams).

13. Disability policy statement

In compliance with the Americans with Disabilities Act Amendments Act(ADAAA), students who require reasonable accommodations due to a disability to properly execute coursework must register with Student Accessibility Services (SAS) in Boca Raton, SU 133 (561- 297-3880), in Davie, LA 131 (954-236-1222) or in Jupiter, SR 111F (561-799-8585) and follow all SAS procedures.

14. Honor code 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 unfair advantage over any other. Academic dishonesty is also destructive of the university community, which is grounded in a system of mutual trust and place high value on personal integrity and individual responsibility. Harsh penalties are associated with academic dishonesty. See University Regulation 4.001 at
www.fau.edu/regulations/chapter4/4.001_Code_of_Academic_Integrity.pdf

15. Required texts/reading

C.T. Chen, "Linear System Theory and Design", 4th edition, Oxford University Press, 2013

16. Supplementary/recommended readings

17. Software: MATLAB with Control Systems Toolbox and Simulink

18. Course Lectures:

EEL 5613 – Modern Control (Fall 2018)
Course Calendar Version 1.0 (11/28/2017)

Week / Lecture #	Date	Topics *Computer activities are shown in italic letters*	Comments
1/1	T 8/21	Course Introduction; Syllabus and grading policy; General Course Introduction; State-Variable Representations: Phase Canonical Form for all-pole transfer functions, State variable model for a RLC circuit, Phase Canonical form for transfer functions with zeros	

1/2	Th 8/23	State Variable Model: Diagonal Form, Model for a multi-input multi-output compound system with state variable subsystem models; From State-Variable Representation to Transfer Function Matrix Representation; Basic Concepts in Linear Algebra: Fields, Vector Spaces; Examples *Control Systems Toolbox Tutorial: tf, zpk and ss lti blocks, the ltiview GUI*	HW1 given (State Variables, Some Linear Algebra: linearly independent vectors, matrix rank and nullity)
2/3		Basic Concepts in Linear Algebra: Linearly Independent Vectors, The Dimension of a Vector Space, Basis of a Vector Space, Linearly Independent Vectors that Form a Basis; *Simulink Tutorial: Construction of a State Variable Model*	
2/4		*Simulink Tutorial (cont'd): Construction of state variable model using scalar state and output equations, the state-variable model block;* Basic Concepts in Linear Algebra: Vector Representation w.r.t a Basis; Change of Basis, Linear Operators, Mapping of Vector Spaces	
3/5		Basic Concepts in Linear Algebra: Similarity Transformation, The Distinction Between an Operator and its Representation; Linear Algebraic Equations, Range Space, Rank of a Matrix, Nonsingular Matrices and Full Rank, Null Space, The Range Space and Null Space of a Matrix, Condition for Linearly Independent Solutions of Linear Algebraic Equations	
3/6		Basic Concepts in Linear Algebra: Sylvester's Inequality and Corollaries; Eigenvalues and Eigenvectors, Poles of Transfer Function Matrix and System Stability; Distinct Eigenvalues and Diagonal State-variable Representation	HW2 given (Some more Linear Algebra: Eigenvalues and eigenvectors, Diagonal matrices and Jordan Canonical Form, Functions of

			Square Matrices, Matrix Norms, Solution of State Equations)
4/7		Basic Concepts in Linear Algebra: Non-Distinct Eigenvalues and the Jordan Canonical Form, Generalized Eigenvectors, Linearly Independent Eigenvectors Associated with an Eigenvalue that has Multiplicity, Jordan Canonical Form Via Similarity Transformation; Powers of Square Matrices, Caley-Hamilton Theorem, Function of a Square Matrix	
4/8		Basic Concepts in Math: Inner Product of Vector Spaces; Norms; Back to Control: Homogeneous Linear Time Varying State Equation: Uniqueness & Existence of a Solution, The Transition Matrix	HW1 due
5/9		The Peano-Baker series, Particular Cases of the Transition Matrix, Properties of the Transition Matrix: Composition Rule of Transition Matrices, Inverse of the Transition Matrix; Solution of the Homogeneous Linear Time Invariant State Equation; The Solution Space, Modes of the System, Stable and Unstable Subspaces	
5/10		Inhomogeneous Linear Time-Varying State Equation: Unique Solution via the Variation of Constants Formula; Equivalent Time-Invariant Linear Dynamical Equations and Transfer Function Matrix; Introduction to the Concepts of Controllability and Observability; Simple Examples	
6/11		Controllability - Simple example (cont'd) Some More Math Background: Geometric Interpretation for Existence of Solution to Linear Algebraic Equations, Symmetric Matrix, Positive Definite Matrix, Non-Negative Definite Matrix; Controllability of Linear Time-Varying	HW2 due

		Systems: Introduction; Controllability of Linear Time-Varying Systems: Lemma about Controllability of system in which A(t)=0	
6/12		Controllability of Linear Time-Varying Systems: Derivation of the Controllability Gramian, Symmetry Property of Gramians; Controllability of Linear Time-Invariant Systems – The Controllability Rank Criterion; Examples; The Controllability Index	
7/13		Relationship Between Controllability and Choice of State-Variable Representation; Controllability Canonical Decomposition Theorem – Significance; Controllability Canonical Decomposition Theorem – Proof Stabilizability of Linear Time-Invariant Systems: Results related to the Controllable Subspace	
7/14		The Connection Between Stabilizability, Unstable Subspace and Controllable Subspace; Examples; Observability of Linear Time-Varying Systems: The Observability Gramian, Duality of Controllability and Observability	HW3 given (Controllability, Observability, Stabilizability)
8/15		Review for the Midterm (covering the material of HW1 and HW2), old midterm problems; Examples: Controllability and Observability	
8/16		Observability of Linear Time-Invariant Systems: The Rank Criterion; Observability Canonical Decomposition Form Canonical Decomposition Theorem; State Feedback in Linear Time-Invariant Systems: Open-Loop vs. Closed-Loop Controllability, Extension to Multi-Input Time-Varying Systems; SISO Pole Placement Theorem: State Feedback for System in Controllable Canonical Form	
9		**Midterm Exam**	
9/17		Ackermann's Formula for SISO Pole Placement;	

		Heymann's Lemma: Pole Placement in MIMO Systems	
10/18		Original Proof of heymann's Lemma (Cont'd); Hautus' Extension to Heymann's Lemma; Proof that Pole Placement implies Controllability; Pole Placement in Systems that are not Fully Controllable; Non-Preservation of Observability Under State Feedback; Pole-Zero Cancellation	HW3 due HW4 given (State Feedback, Observers, Separation Principle)
10/19		State Feedback by means of Lyapunov Equation; Open Loop State Estimation – why not; Full-Order Observers: Estimation Error, Conditions for Observer Existence, Observer Design Algorithm	
11/20		Connection Between State Feedback and Observer Design – The Separation Principle, Proof of the Separation Principle; Reduced-Order Observer Design	
11/21		Full-Order and Reduced-Order Observer Design by means of Lyapunov Equation; Introduction to Least-Squares Unconstrained Optimal Control: Types of Control Problems – Minimum Time, Terminal Control, Minimum Energy, Tracking, The Regulator Problem	
12/22		Linear Quadratic Regulators: The Time-Varying Riccati Equation, Optimal Control Law; Time Invariant Quadratic Regulators – Finite vs. Infinite Time Horizon	
12/23		Linear Quadratic Regulators – Examples	
13/24		Properties of the Algebraic Riccati Equation	HW4 due
13/25		Feedback Stabilization by means of the Algebraic Riccati Equation; Minimum Control Energy Optimal Control; Optimal Tracking Control - Introduction	HW5 given (Least Squares Optimal Control)
13	**F 11/16**	**W Grade Deadline**	
14/26		Realization Theory: Standard Controllable and Standard Observable Realizations; McMillan Degree and Minimal Realization	
14	**Th 11/22**	**Thanksgiving Holiday**	
15/27		Brief Overview of Kalman Filters and	

		Discrete-Time Systems	
15/28		Review for the Final Exam	HW5 due
16		**Final Exam** Covers the material of HW3-HW5	