AME 541 Syllabus - Fall 2018

Instructor: Prof. Néstor O. Pérez-Arancibia (perezara@usc.edu)

Class Formal Name: Linear Control Systems II
Class Nickname: Linear System Theory
Instructor Phone Number: 310-384-0123
Lecture Time: Tuesdays and Thursdays, 5:00-6:20 PM
Lecture Location: OHE-122
Discussion Time: Fridays, 12:00-12:50 PM
Discussion Location: OHE-100C
Instructor Office Hours: Mondays, 2:00-4:00 PM (OHE 430-I or PCE-210). DEN students can connect via Skype or similar system (Mondays, 2:00-4:00 PM, CA time).

Teaching Assistant: Ke Xu (kexu@usc.edu)
TA Office Hours: Mondays and Thursdays, 3:00-5:00 PM (VHE-202). DEN students can connect via Skype (Mondays and Thursdays, 3:00-5:00 PM, CA time).

Formal Prerequisite: AME 451 (Linear Control Systems I)

Recommended Prerequisites: Linear Algebra; Differential Equations; Basic Probability Theory; Signals & Systems; Basic Real Analysis; Basic Programing using MATLAB® and SIMULINK®.

Textbook (Not Required for Homework): [1] Chi-Tsong Chen, *Linear System Theory and Design*, New York, NY and Oxford, UK: Oxford University Press, 2013 (4th Edition).

Other References (Not Officially Required):

- [2] João P. Hespanha, *Linear Systems Theory*, Princeton, NJ and Oxford, UK: Princeton University Press, 2009.
- [3] Geir E. Dullerud and Fernando Paganini, *A Course in Robust Control Theory*, New York, NY: Springer, 2000.
- [4] Thomas Kailath, *Linear Systems*, Englewood, NJ: Prentice-Hall, 1980.
- [5] Kemin Zhou and John C. Doyle, *Essentials of Robust Control*, Upper Saddle River, NJ: Prentice-Hall, 1998.
- [6] Gilbert Strang, *Introduction to Linear Algebra*, Wellesley, MA: Wellesley-Cambridge Press, 2009 (4th Edition).
- [7] Gilbert Strang, *Linear Algebra and Its Applications*, Brooks/Cole, 2006.
- [8] T. S. Blyth and E. F. Robertson, *Basic Linear Algebra*, London, UK: Springer, 1998.
- [9] T. S. Blyth and E. F. Robertson, *Further Linear Algebra*, London, UK: Springer, 2002.
- [10] Alan V. Oppenheim and Alan S. Willsky, *Signals and Systems*, Upper Saddle River, NJ: Prentice-Hall, 1997.

- [11] Alberto Leon-Garcia, *Probability and Random Processes for Electrical Engineering*, Reading, MA: Addison-Wesley, 1994.
- [12] Thomas Kailath, Ali H. Sayed and Babak Hassibi, *Linear Estimation*, Upper Saddle River, NJ: Prentice-Hall, 2000.
- [13] Harry Dym, *Linear Algebra in Action*, Providence, RI: American Mathematical Society, 2013.

Course Objectives:
This course discusses the fundamental topics in *linear systems* upon which *modern control theory, linear estimation (Kalman filtering)* and *linear robust control theory* have been developed. At the end of the semester, the students will be proficient in the most important topics in linear systems theory, including *system representation*, *stability*, *controllability*, *observability, realization theory*, *basic deterministic state estimation* and *basic state feedback control*. Also, some introductory notions on *LQR control*, *Kalman filtering*, *LQG control*, and *LTI system-order reduction* will be briefly discussed.

Grading:
5% Quiz #1 (September 07, 2018 at discussion time: 12:00-12:50 PM)
5% Quiz #2 (October 19, 2018 at discussion time: 12:00-12:50 PM)
10% Homework
20% Midterm Exam #1 (September 27, 2018 at lecture time: 5:00-6:20PM)
20% Midterm Exam #2 (November 08, 2018 at lecture time: 5:00-6:20PM)
40% Final Exam (December 06, 2018, 4:30-6:30 PM)

If for some reason you are not able to take one or more of the tests administrated previously to the Final Exam (i.e., Quiz #1, Quiz #2, Midterm #1, Midterm #2), the corresponding percentage is automatically added to the Final Exam's percentage. For example, if you miss Quiz #1, the weight of your Final Exam would be 45% instead of 40%. If you like (not recommended) you can take the final test only, which in that case would weigh 90% of your semester grade. Consistent with this policy, it also follows that if the score of a test administrated previously to the Final Exam (i.e., Quiz #1, Quiz #2, Midterm #1, Midterm #2) is lower than your score in the Final Test, the Final Test score will be used to compute your final grade. The pedagogical justification for this policy is that what really matters are your aggregated abilities and knowledge at the end of the semester. **Notice that this is a very favorable policy for conscientious, responsible students and extremely risky for students that leave everything for the last minute. So, use the rules wisely in your favor!**

Homework:
Homework is assigned weekly on Fridays by 11:59 PM, CA time, and due on Fridays of the following week at 11:59 PM, CA time. **Please check the DEN blackboard regularly for homework updates addressing questions and comments from students in the class.** Late submissions will not be graded and will receive a score of 0 (zero). While working on your homework you are allowed to talk to the teaching assistant (TA) and your classmates. Also, it is allowed to look at material on-line such as Wikipedia. However, you **must** write down your own solutions, using your own words and justifying your ideas. Therefore, copied or copy-and-pasted

solutions from other sources (classmates, books, on-line material, etc.) will be considered an academic integrity violation.

During the semester, **14 (fourteen)** weekly homework assignments will be given. Each weekly assignment will have **at least 100 achievable points** so that at the end of the semester the aggregated amount of achievable points will be **at least 1400 (one thousand four hundred). A thousand (1000) points** are required for a 100% of the homework credit.

Midterm and Final Exams:
The Quizzes, Midterm Exams and Final Exam are **open-book/open-notes**. Talking on the phone, texting, emailing, communicating in any way with other people or similar activities are not allowed during the tests. **You should bring your own exam booklet (or abundant amounts of paper).** The policy regarding the use of calculators, laptops and MATLAB® is contingent to the specific situation and will be announced in class.

Academic Integrity:
All cases of academic integrity violation will be referred by a written report to the Student Judicial Affairs and Community Standards (http://www.usc.edu/student-affairs/SJACS/). The typical penalty recommended by SJACS is a grade of F for the course. **Also, see Appendix in page 8.**

Computer Software:
MATLAB® and SIMULINK®, which can be downloaded from the USC IT website. These are computer tools required for solving some of the homework questions and take-home exam questions.

Programmed Lectures and Discussions

Week	Date	Topics	References	Comments
1	Aug. 21	**Lecture 1:** • Signals and Systems; • Linearity, time invariance and causality; • Zero-state LTI system response and convolution.	• **Slides;** • **Ch2 in [1];** • Ch1 in [2]; • [10].	
1	Aug. 23	**Lecture 2:** • Review of the Laplace transform; • Representation of zero-state LTI systems using transfer functions; • State-space representation of LTI systems.	• **Slides;** • **Ch2 in [1];** • Ch1 in [2]; • [10].	
1	Aug. 24	**Discusion 1:** • LTI mechanical example; • LTI electrical example; • Hints for HW 1.		**HW 1 (A)**

2	Aug. 28	**Lecture 3:** • Discrete-time LTI systems; • Linear systems versus nonlinear systems; • Linearization;	• **Slides;** • **[1].**	
2	Aug. 30	**Lecture 4 (Math Review):** • Basic logic and methods of proof; • Vector spaces and the concept of subspace; • Basic matrix algebra; • Fundamental linear algebra facts (theorems).	• **Slides;** • **Ch3 in [1];** • Ch3 in [6]; • Ch3 in [7]; • Ch1 in [3]; Ch5 in [8].	
2	Aug. 31	**Discusion 2:** • Discrete-time system example; • Linear algebra example; • Hints for HW 1 and HW 2.		**HW 2 (A); HW 1 (D).**
3	Sep. 04	**Lecture 5 (Algebra + Controls):** • Similarity Transformations; • Diagonal and Jordan forms.	• **Slides;** • **[1];** • [2]; • [3].	
3	Sep. 06	**Lecture 6:** • Functions of square matrices; • Cayley-Hamilton theorem; • Methods to find functions of square matrices.	• **Slides;** • **[1];** • [2]; • [3]; • [4].	
3	Sep. 07	**Quiz 1**		**HW 3(A); HW 2 (D).**
4	Sep. 11	**Lecture 7:** • The function e^{At}; • Properties of e^{At}.	• **Slides;** • **[1].**	
4	Sep. 13	**Lecture 8:** • Solution of the continuous-time LTI state-space equations; • Solution of the discrete-time LTI state-space equations.	• **Slides;** • **[1];** • [2]; • [3]; • [4].	
4	Sep. 14	**Discusion 3:** • Properties of e^{At} example; • Solution of LTI state-space equations example; • Hints for HW 3 and HW 4.		**HW 4 (A); HW 3 (D).**
5	Sep. 18	**Lecture 9:** • Algebraic Equivalence; • The concept of realization.	• **Slides;** • **[1].**	
5	Sep. 20	**Lecture 10:** • Continuous-time internal Stability; • Continuous-time Lyapunov theorem for LTI stability — Part 1.	• **Slides;** • **[1].**	

5	Sep. 21	**Discusion 4:** • Internal stability examples; • Application of the Lyapunov theorem example; • Hints for HW 3 and HW 4.		**HW 5 (A);** **HW 4 (D).**
6	Sep. 25	**Lecture 11:** • Continuous-time Lyapunov theorem for LTI stability — Part 2.	• **Slides;** • **[1].**	
6	Sep. 27	**Midterm Exam 1**		
6	Sep. 28	**Discusion 5:** • Internal stability examples; • Applications of the Lyapunov theorem example; • Hints for HW 5 and HW 6.		**HW 6 (A);** **HW 5 (D).**
7	Oct. 02	**Lecture 12:** • Discrete-time internal Stability; • Discrete-time Lyapunov theorem for LTI stability.	• **Slides;** • **[1].**	
7	Oct. 04	**Lecture 13:** • Continuous-time input-output stability.	• **Slides;** • **[1].**	
7	Oct. 05	**Discusion 6:** • Discrete-time internal stability examples; • Applications of the discrete-time Lyapunov theorem example; • Continuous-time input-output stability examples; • Hints for HW 6 and HW 7.		**HW 7 (A);** **HW 6 (D).**
8	Oct. 09	**Lecture 14:** • Discrete-time input-output stability.	• **Slides;** • **[1].**	
8	Oct. 11	**Lecture 15:** • Continuous-time controllability — Part 1.	• **Slides;** • **[1].**	
8	Oct. 12	**Discusion 7:** • Discrete-time input-output stability examples; • Continuous-time controllability examples; • Hints for HW 7 and HW 8.		**HW 8 (A);** **HW 7 (D).**
9	Oct. 16	**Lecture 16:** • Continuous-time controllability — Part 2.	• **Slides;** • **[1].**	
9	Oct. 18	**Lecture 17:** • Kalman decomposition.	• **Slides;** • **[1].**	
9	Oct. 19	**Quiz 2**		**HW 9 (A);** **HW 8 (D).**

10	Oct. 23	**Lecture 18:** • Controllability examples.	• **Slides;** • **[1].**	
10	Oct. 25	**Lecture 19:** • Continuous-time observability.	• **Slides;** • **[1].**	
10	Oct. 26	**Discusion 8:** • Continuous-time controllability examples; • Continuous-time observability examples; • Hints for HW 9 and HW 10.		**HW 10 (A);** **HW 9 (D).**
11	Oct. 30	**Lecture 20:** • Minimal realizations.	• **Slides;** • **[1].**	
11	Nov. 01	**Lecture 21:** • Discrete-time controllability; • Discrete-time observability.	• **Slides;** • **[1].**	
11	Nov. 02	**Discusion 9:** • Minimal realizations examples; • Discrete-time controllability and observability examples; • Hints for HW 10 and HW 11.		**HW 11 (A);** **HW 10 (D).**
12	Nov. 06	**Lecture 22:** • Singular value decomposition (SVD); • Balanced realizations — Part 1.	• **Slides;** • **[1].**	
12	Nov. 08	**Midterm Exam #2**		
12	Nov. 09	**Discusion 10:** • SVD examples; • Balanced realizations examples; • Hints for HW 11 and HW 12.		**HW 12 (A);** **HW 11 (D).**
13	Nov. 13	**Lecture 23:** • Balanced realizations — Part 2; • Balanced truncation.	• **Slides;** • **[1].**	
13	Nov. 15	**Lecture 24:** • The notion of state feedback; • State feedback controllers.	• **Slides;** • **[1].**	
13	Nov. 16	**Discusion 11:** • Balanced truncation example; • State feedback example; • Hints for HW 12 and HW 13.		**HW 13 (A);** **HW 12 (D).**
14	Nov. 20	**Lecture 25:** • Introduction to LQR control; • Simple LQR design example.	• **Slides;** • **[1].**	
14	Nov. 22	**Thanksgiving**		
14	Nov. 23	**Thanksgiving**		**HW 14 (A);** **HW 13 (D).**

15	Nov. 27	**Lecture 26:** • The notion of observer; • Simple deterministic observers.	• **Slides;** • **[1].**	
15	Nov. 29	**Lecture 27:** • Introduction to Kalman filtering; • Simple Kalman filter design.	• **Slides;** • **[1].**	
15	Nov. 30	**Discusion 12:** • Simple LQR example; • Simple Kalman filter example; • Hints for HW 14.		**HW 14 (D).**
16	Dec. 06	**Final Exam**		**4:30PM to 6:30PM**

Document first uploaded on August 16, 2018.
The contents of this syllabus are subject to change. Weekly information will be updated without notice. Change in policies, important dates, and homework content will be announced in class.

Prof. Néstor O. Pérez-Arancibia

APPENDIX: Statement on Academic Conduct and Support Systems

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Section 11, *Behavior Violating University Standards* https://scampus.usc.edu/1100-behavior-violating-university-standards-and-appropriate-sanctions. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the *Office of Equity and Diversity* http://equity.usc.edu or to the *Department of Public Safety* http://capsnet.usc.edu/department/department-public-safety/online-forms/contact-us. This is important for the safety of the whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. *The Center for Women and Men* http://www.usc.edu/student-affairs/cwm/ provides 24/7 confidential support, and the sexual assault resource center webpage http://sarc.usc.edu describes reporting options and other resources.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.html provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information http://emergency.usc.edu* will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.