EE593, Robust Multivariable Control
Units: 04
Primary audience: MS and PhD students
Term: Fall
Day: Tu, Th
Time: 5:00-6:50 pm

Note: This course has been upgraded to a 4-unit course. This coming fall will be the first time it is taught in the 4-unit format. Note that, contrary to undergraduate classes, we are following the traditional schedule [https://viterbigrad.usc.edu/](https://viterbigrad.usc.edu/) starting Aug 24. The last day of class still needs to be confirmed. Because of the uncertain situation with COVID-19, things might still change; therefore, please, check the blackboard on a regular basis.

Location: Class was initially supposed to be “hybrid,” with SLH 100 reserved, but because of the worsening COVID-19 situation, it will most likely be “online.”

Instructor: E. Jonckheere
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Office: EEB306
Office Hours: Tu & Th 2:00-4:00 pm (probably through Skype)
Contact Info: jonckhee@usc.edu (expect reply to email within 48 hours) or Skype: edmond.jonckheere

Teaching Assistant or Mentor: TBA
Office: TBA
Office Hours: TBA
Contact Info: TBA

IT Help: Distance Education Network (DEN)
Hours of Service:
Contact Info: dentsc@usc.edu
(213)740-9356
Course Description

Theoretical concepts will be put into practice by a benchmark space structure example that would serve as culmination of the class. Other cutting edge applications that could be considered include power grid and quantum communication control (depending on students’ interests.)

This is a course “beyond the basics,” for on-campus students eager to get into the deeper conceptual foundations of control and for those students from industry in need of learning the modern control design methods.

Learning Objectives
Students will be able to design controllers for many-input, many-output systems with guaranteed robustness against model uncertainty. In addition, students will become acquainted with the mathematical principles (e.g., complex function theory, Principle of Optimality, Game theory) behind the practical design methods.

Prerequisite(s): EE482 (Linear Control Systems) and EE585 (Linear System Theory)
Co-Requisite(s): EE585 (Linear System Theory). While it is preferred that the student has already taken EE585 before embarking in EE593, taking EE585 concurrently is acceptable.
Concurrent Enrollment: N/A
Knowledge of Nonlinear & Adaptive Control on the level of EE587 is recommended but not required.

Course Notes
Grading Type: letter grade
The course will most probably be “online,” through webex.
Copies of lecture slides and other class information will be posted on Blackboard.
Classroom utilization of Matlab and Mathematica will be used as multimedia/technology-enhanced learning strategies.

Technological Proficiency and Hardware/Software Required
Students will be assumed to be familiar with Matlab. However, this class also involves polynomial matrix manipulations for which Mathematica is best. Students will be asked to install Mathematica on their computer and a “crash course” in Mathematica will be given.

Required Readings and Supplementary Materials
Additional (required) reading:

Required textbook will be available through the USC bookstore. Additional recommended text can be obtained through Amazon (https://www.amazon.com/Multivariable-Feedback-Control-Analysis-Design/dp/0470011688/ref=asc_df_0470011688/?tag=hyprod-20&linkCode=df0&hvadid=266179548166&hvpos=1o1&hvnetw=g&hvrand=1058707744440463224&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=&hvtargid=pla-453711516850&psc=1) or Barnes & Noble (https://www.barnesandnoble.com/p/multivariable-feedback-control-sigurd-skogestad/1101200631/2662170539643?st=PLA&sid=BN_BDL+Marketplace+Good+Used+Textbooks+-+Desktop+Low&sourceId=PLAGoNA&dpid=tdtve346c&2sid=Google_c&gclid=EAalQobChMIu_PHrNyPSQIV6R-tBh0V5b0EAQYAIABEgLxYvD_BwE). The additional readings will be made available through the blackboard.

**Description and Assessment of Assignments**

Students will be assigned a homework every other week. Homework will consist in solving textbook problems and will include a “research-oriented” problem to probe and stimulate students’ creativity. There will be one midterm and one final.
Grading Breakdown

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Points</th>
<th>% of Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>participation</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>homework</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>midterm</td>
<td>35%</td>
<td></td>
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<tr>
<td>final</td>
<td>40%</td>
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<tr>
<td>TOTAL</td>
<td>0</td>
<td>1</td>
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Grading Scale (Example)
Course final grades will be determined using the following scale (subject to “curving.”)

- A: 90-100
- A-: 80-90
- B+: 75-80
- B: 70-75
- B-: 65-70
- C+: 63-65
- C: 60-63
- C-: 58-60
- D+: 55-58
- D: 53-55
- D-: 50-53
- F: 50 and below

Assignment Rubrics
N/A

Assignment Submission Policy
Homework assigned on Tuesday (or first day of class of the week), to be submitted two weeks after assignment, same day of the week. Late assignments will be penalized (10%), unless valid reason, e.g., medical problem, family or other emergency.

Grading Timeline
Graded homework are expected to be returned within one week.

Additional Policies
Attendance of the lectures is expected. Matlab and Mathematica will be used in the classroom. Cellphones are to be turned off before beginning of class.
## Course Schedule: A Weekly Breakdown

<table>
<thead>
<tr>
<th>Week</th>
<th>Topics/Daily Activities</th>
<th>Readings and Homework</th>
<th>Deliverable/ Due Dates</th>
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</thead>
<tbody>
<tr>
<td><strong>Week 2</strong>, starting Aug. 31</td>
<td>Review of linear algebra &amp; systems. Matrix inversion lemma and application to modern architecture for structured uncertainties, singular values, controllability, observability, realization, interconnected systems</td>
<td>Zhou-Doyle, Chapters 2, 3</td>
<td>Homework #1 assigned</td>
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<tr>
<td><strong>Week 3</strong>, starting Sept. 7</td>
<td>Closed-loop (internal) stability; multivariable Nyquist stability criterion; uncertainty modeling; review of classical gain &amp; phase margins and multivariable extensions; Bode singular value plots of sensitivity and complementary sensitivity matrices; structured singular values in both cases of complex and real perturbations, complex-analytic theory of ( \mu )-function, application of Carathéodory boundary behavior of conformal maps, structured singular values plots and its applications to quantum control.</td>
<td>Zhou-Doyle, Sections 2.6, 6.1-6.3, Chapters 5, 8</td>
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<tr>
<td><strong>Week 4</strong></td>
<td>Fundamental limitations</td>
<td>Zhou-Doyle, Sections 6.4, 6.5</td>
<td>Homework #1 due,</td>
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<tr>
<td>Week 5, starting Sept. 21</td>
<td>Frobenius norm; elementary parametric design; notion of power spectral density; H-two versus H-infinity design</td>
<td>Handout provided by instructor</td>
<td>Homework #2 due, Homework #3 assigned</td>
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<tr>
<td>Week 6, starting Sept. 28</td>
<td>Algebraic foundation of multivariable theory: Smith-McMillan form; multivariable poles/zeros; notion of rational coprime factorization; Bezout identity; crash course in MATHEMATICA</td>
<td>Zhou-Doyle, Section 5.4. Zhou-Doyle, Chapter 11.</td>
<td>Homework #3 assigned</td>
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<tr>
<td>Week 7, starting Oct. 5</td>
<td>Historical development of H-infinity; Nevanlinna – Pick interpolation; all-pass property; Nehari extension, Hankel operators, Sarason’s contractive dilation, parameterization of all stabilizing controllers; Q-parameter solution to H-2 and H-infinity problems.</td>
<td>Zhou-Doyle, Chapter 13</td>
<td>Homework #3 due Midterm week</td>
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<td>Week 8, starting Oct. 12</td>
<td>Bellamn’s Principle of Optimality; the linear-quadratic regulator problem</td>
<td>Zhou-Doyle, Chapter 13</td>
<td>Homework #4 assigned</td>
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<td>Week 9, starting Oct. 19</td>
<td>Algebraic Riccati equation and its computational solutions</td>
<td>Zhou-Doyle, Chapter 13</td>
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<td>Week 10, starting Oct 26</td>
<td>Bounded real lemma; positive realness and circuit theory interpretation; dissipation as hysteresis in stress-strain diagram, in space structures. Introduction to smart materials.</td>
<td>Notes provided by instructor [SJVL]; Zhou-Doyle Example 4.2, Section 12.4</td>
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<tr>
<td>Week 11, starting Nov. 02</td>
<td>Bounded real lemma approach to H-infinity design</td>
<td>Notes provided by instructor [SJVL]; Zhou-Doyle Example 4.2, Section 12.4</td>
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</table>
Midterm and final are sit-down, open books & open notes exams with laptops to solve design problems.
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 Part B, Section 11, “Behavior Violating University Standards” https://policy.usc.edu/scampus-part-b/. 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.

Support Systems:
Counseling and Mental Health - (213) 740-9355 – 24/7 on call studenthealth.usc.edu/counseling/
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

National Suicide Prevention Lifeline - 1 (800) 273-8255 - 24/7 on call http://www.suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-9355(WELL), press "0" after hours - 24/7 on call https://studenthealth.usc.edu/sexual-assault/
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED) - (213) 740-5086/Title IX - (213) 821-8298 https://equity.usc.edu/, http://titleix.usc.edu/
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298 https://usc-advocate.symplicity.com/care_report/
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity | Title IX for appropriate investigation, supportive measures, and response.

The Office of Disability Services and Programs - (213) 740-0776 http://dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

USC Campus Support and Intervention - (213) 821-4710 https://uscsa.usc.edu/
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.
Diversity at USC - (213) 740-2101
https://diversity.usc.edu/
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
http://dps.usc.edu/,  http://emergency.usc.edu
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-1200 – 24/7 on call
http://dps.usc.edu
Non-emergency assistance or information.