USC Viterbi School of Engineering

EE593, Robust Multivariable Control
Units: 03
Term: Fall 2018; Day: Tue, Thu; Time: 5:00-6:20 pm

Location: DEN, OHE120

Instructor: E. Jonckheere
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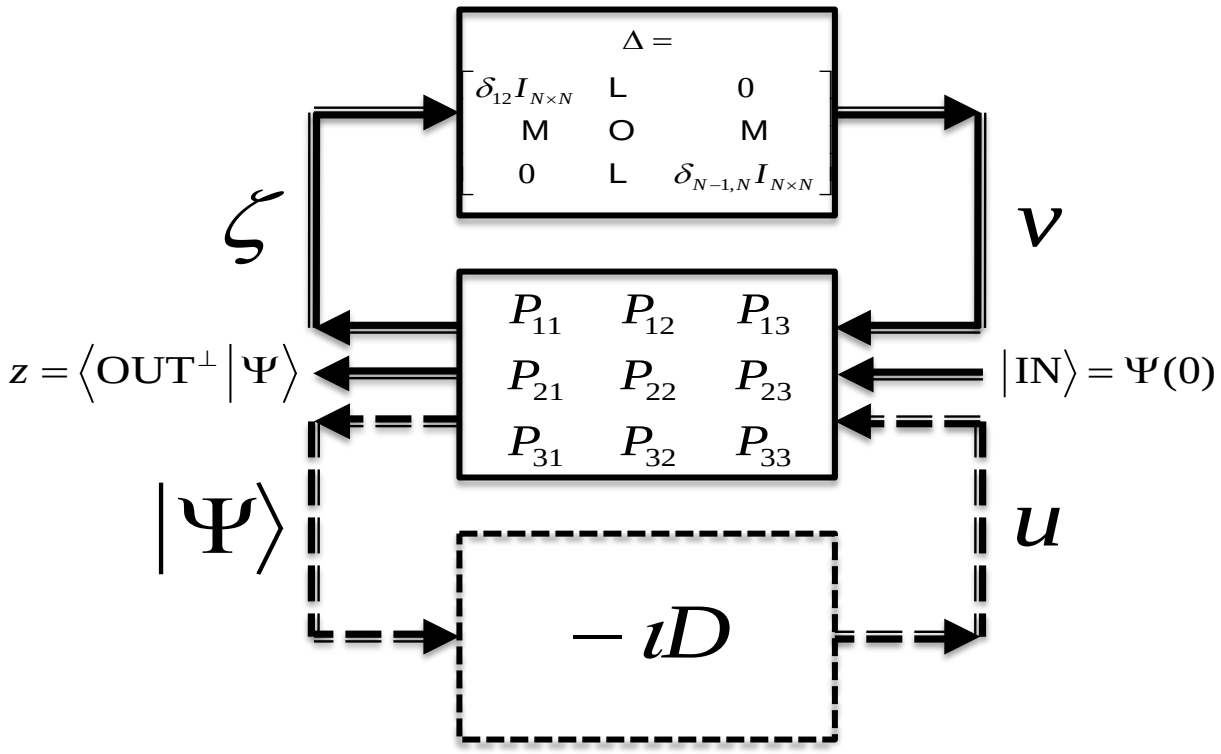
IT Help: Group to contact for technological services, if applicable.
Hours of Service:
Contact Info: Email, phone number (office, cell), Skype, etc.



Quantum control illuystration of robust multivariable control

Course Description

Review of various robust multivariable control architectures (centralized, decentralized, networked). Sensitivity and complementary sensitivity matrices; uncertainty representation; singular values Bode plots. Multivariable Nyquist stability criterion, internal stability, parameterization of stabilizing controllers. Algebraic Riccati Equations. Linear Quadratic regulator, Bounded Real Lemma approach to modern H-infinity design. Adverserial game approach to modern H-infinity design.

As cutting edge applications, we will consider power grid and quantum communication control.

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 sytems 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)

Course Notes

Grading Type: letter grade
The course is Web-Enhanced **(Blackboard)**.
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

Required textbook: Kemin Zhou and John C. Doyle, *"Essentials of Robust Control."* Prentice Hall, Upper Saddle River, NJ, 1998. ISBN 0-13-525833-2.
Additional recommended text: Sigurd Skogestad and Ian Postlethwaite, *"Multivariable Feedback Control: Analysis and Design,"* 2nd Edition, Wiley, Nov. 2005, ISBN: 978-0-470-01167-6.
Additional (required) reading:

- [PAJ] Ian R. Petersen, Brian D.O. Anderson and Edmond A. Jonckheere, ``A first principles solution to the nonsingular control problem," *International Journal on Robust and Nonlinear Control,* vol. 1, pp. 171-185, 1991.
- [SJVL] M. G. Safonov, E. A. Jonckheere , M. Verma, D. J. N. Limebeer, "Synthesis Of Positive Real Multivariable Feedback Systems," *International Journal of Control,* Vol. 45, Issue 3, pp. 817-842, 1987.
- [WJ] Bing-Fei Wu and Edmond A. Jonckheere, "A simplified approach to Bode's theorem for continuous-time and discrete-time systems", *IEEE Transactions on Automatic Control*, volume AC-37, number 11, pp. 1797-1802, November, 1992.

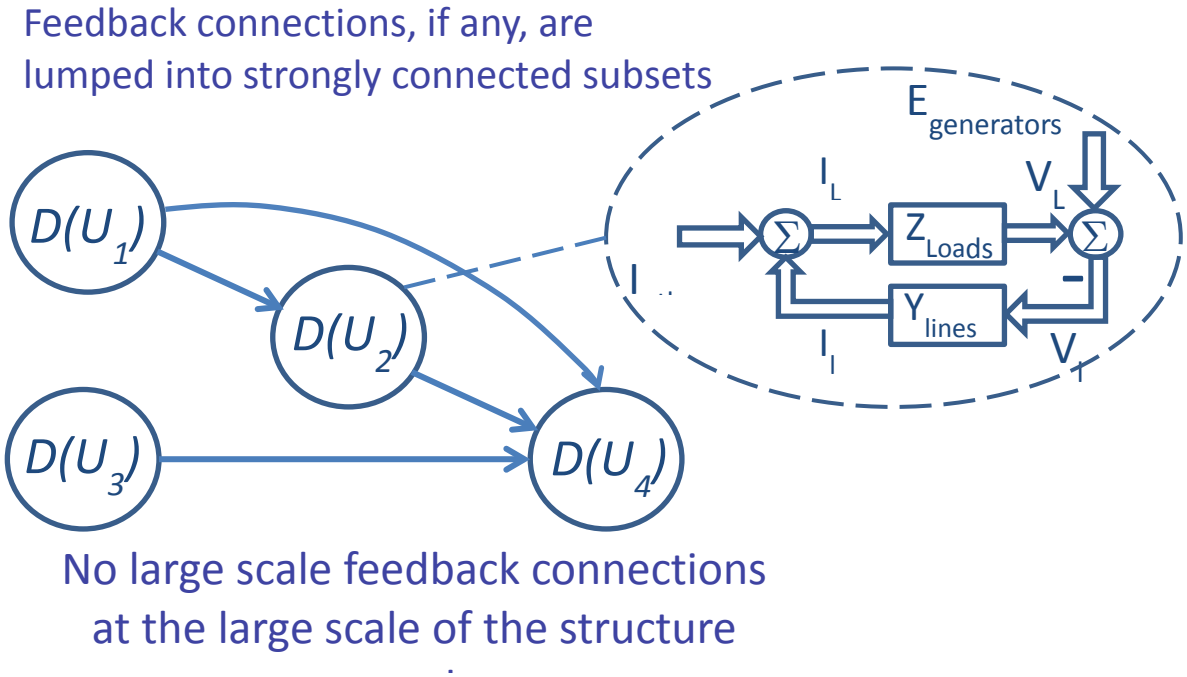
Description and Assessment of Assignments
Students will be assigned a homework every other week. Homework will consist in solving textbook problems and will include a "research-oriented" problem to probe and stimulate students' creativity. There will be one midterm and one final.

Grading Breakdown

Assignment	Points	% of Grade
participation		5%
homework		20%
midterm		35%
final		40%
TOTAL	0	1

Assignment Submission Policy
Homewo rk to be submitted two weeks after assignment.

Additional Policies
Late assignments will be penalized (unless valid, e.g., medical, reason).
Attendance of the lectures is expected.
Matlab and Mathematica will be used in the classroom.



Power grid illustration of robust multivariable control

Course Schedule: A Weekly Breakdown

	Topics/Daily Activities	Readings and Homework	Deliverable/ Due Dates
Week 1 Begin Aug. 20	Various **architectures** of control systems (classical, modern, centralized, decentralized, networked). Concepts of feedback performance, **uncertainty and robustness**. Power grid & Quantum communication & Transmission Control Protocol (TCP) applications	Zhou-Doyle, Chapter 1	
Week 2 Begins Aug. 27	Review of linear algebra & systems. Matrix inversion lemma, singular values, controllability, observability, realization, interconnected systems	Zhou-Doyle, Chapters 2, 3	Homework #1 assigned
Week 3 Sept. 03	Closed-loop (internal) stability; **multivariable Nyquist stability criterion**; uncertainty modeling; review of classical gain & phase margins and multivariable extensions; **Bode singular value plots** of sensitivity and complementary sensitivity matrices; structured singular values and its applications to quantum control.	Zhou-Doyle, Sections 2.6, 6.1-6.3, Chapters 5, 8	
Week 4 Sept. 10	**Fundamental limitations** on achievable feedback performance	Zhou-Doyle, Sections 6.4, 6.5	Homework #1 due, Homework#2 assigned.
Week 5 Sept. 17	Frobenius norm; elementary parametric design; notion of power spectral density; H-two versus H-infinity design	Handout provided by instructor; Zhou-Doyle, Chapter 4	
Week 6 Begins Sept. 24	Algebraic foundation of multivariable theory: **Smith-McMillan form**; multivariable poles/zeros; notion of rational coprime factorization; Bezout identity; crash	Handout provided by instructor	Homework #2 due, Homework#3 assigned.

	course in MATHEMATICA		
Week 7 Begins Oct. 1	Historical development of H-infinity; Nevanlinna – Pick interpolation; **all-pass property;** parameterization of all stabilizing controllers; Q-parameter solution to H-2 and H-infinity problems.	Zhou-Doyle, Section 5.4. Zhou-Doyle, Chapter 11.	
Week 8 Begins Oct. 8	Bellamn's Principle of Optimality; the **linear-quadratic regulator problem**	Zhou-Doyle, Chaper 13	Homework #3 due, No homework assigned because of midterm
Week 9 Begins Oct. 15	**Algebraic Riccati equation**	Zhou-Doyle, Chaper 13	Midterm Oct. 19
Week 10 Begins Oct. 22	**Bounded real lemma**; positive realness and circuit theory interpretation; space structure control example	Notes provided by instructor [SJVL]; Zhou-Doyle Example 4.2, Section 12.4	
Week 11 Begins Oct. 29	Bounded real lemma approach to H-infinity design	Notes provided by instructor [SJVL]; Zhou-Doyle Example 4.2, Section 12.4	Homework #4 assigned
Week 12 Begins Nov. 05	Notion of **adversarial game**: application to control and filtering	Zhou-Doyle, Chapter 14	
Week 13 Begins Nov. 12	Game theoretic/separation approach to **2-Riccati equation solution to H-infinity**.	Zhou-Doyle, Chapter 14	Homework #4 due, Homework#5 assigned.
Week 14 Begins Nov. 19	Various "loop-shifting" techniques to relax conditions for 2-Riccati equation solutions to H-infinity to be applicable.	Zhou-Doyle, Chapter 14	
Week 15 Begins Nov. 26	Review and preparation for final.	N/A	Last homework # 5 due.
FINAL Th. Dec. 06, 4:30-6:30 pm			Date: For the date and time of the final for this class, consult the USC *Schedule of Classes* at www.usc.edu/soc.

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 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 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.htmlprovides 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.