EML 5311 (CAMP,2FED,1FE2) - Spring 2020
Control System Theory

Instructor: Dr. Prabir Barooah
Office: MAE-B 324
E-mail: N/A: see email policy below.

Class date/time: MWF, period 5 (11:45 am - 12:35 pm);
Class location: NEB 201
Office Hours: M, 2:00-3.30 pm, Th 10:00-11:30 am

Course website
Please check the course website in e-learning regularly for updates and announcements.

Teaching Assistant
Austin Coffman
TA office location: MAE-B 227
TA office hours: TBD

Course description
The course is meant to provide a graduate-level introduction to control theory, and the application of the theory to the design of controllers for engineering systems. The material will focus on LTI (linear time invariant) systems, with some discussion on how to apply these techniques developed to the control of non-linear systems.

The following is a tentative list of topics that will be covered in the class.

Part A: Classical control design/analysis through frequency-domain techniques

1. *Dynamic systems* LCCODE (linear, constant coefficient ordinary differential equation) models of dynamic systems, BIBO stability, stabilization through feedback control.
2. *Design for stability and tracking setpoints* PID compensators, design for transient performance through pole placement.
3. *Frequency response* Arbitrary signals as sum of sinusoids, Bode plots, asymptotic tracking of constant and sinusoidal references.
4. *Control design issues/techniques*: Robustness, sensitivity and complementary sensitivity functions, tracking requirements, Loop shaping design. Lead/Lag compensators.
5. *Putting a factor of safety in the design:* Nyquist stability criteria, gain and phase margins.
6. *Data-driven modeling*: System identification from input-output data.

Part A will span approximately 19 lectures.
Part A is on classical control design techniques. The next part, part B, will use modern control design and analysis techniques that use the so-called state space methods. While classical control uses Laplace transforms, modern state space methods operate in the time domain without using transforms.

Part B: Modern control design/analysis techniques (main tool: linear algebra)

1. *Mathematical models of dynamic systems*: State-space description of non-linear dynamic systems, simulations in MATLAB©, equilibrium points, kinds of equilibria, stability of an equilibrium point, Lyapunov stability theorem.

2. *A very brief but intense review of linear algebra*: matrices as linear maps between vector spaces, range and null spaces, four fundamental subspaces, span, basis, linear independence, eigenvalues and eigenvectors.

3. *Linear systems*: linearization around an equilibrium point, linearization around a trajectory, LTI vs LTV systems, Lyapunov vs. BIBO stability of LTI systems, eigenvalues and Lyapunov equation.

4. *State-space design*: Controllability and state feedback, Observability and output-feedback. Luenberger observer, separation principle.

5. *Connections between time domain and Laplace domain*: state-space to transfer function and vice versa (of LTI systems), minimal realization, canonical decomposition.

6. *From C(s) to C-code* Discrete-time systems, sampling and state-space representation, stability. Implementing continuous-time control design through digital computers.

7. *Optimal Control*

   (a) The general optimal control problem.

   (b) *LQR* : The Linear Quadratic Regulator problem, derivation of the ARE and DRE, finite and infinite horizon problems.

Part B will span approximately 24 lectures.

Course prerequisites
Since this course is a *graduate* level introduction to control theory, students are *required* to have taken an undergraduate level controls course. In particular, the students are expected to have an understanding of Laplace transforms and transfer functions. The beginning of Part A will therefore mostly be a quick review, slowing down toward the end when we encounter Nyquist criterion and loop shaping. Part B is expected to be new to all, so no familiarity with this material is expected. Familiarity with MATLAB©is also required, as we will be using it extensively.

Evaluation criteria
For in-campus students, the course letter grade will based on homeworks (20%), Test 1 (20%), Test 2 (20%), Test 3 (20%), and a Project (20%). For the distance students, the course letter grade will based on homeworks (40%) and the Project (60%). There is no end-of-semester final test.
The dates for the tests are:

1. Test 1: February 12 (Wed), Time: 8.30 pm- 10 pm, location: TBD

2. Test 2: March 25 (Wed), Time: 8.30 pm - 10 pm, location: TBD

3. Test 3: April 22 (Wed), Time: 8.30 pm - 10 pm, location: TBD

The dates are subject to change. Any changes to the exam dates will be announced in class and in the course website.

The Project will be take-home, and will be assigned on April 25 (Sat) at 00:00 hrs and will be due on 28th 24:00 hrs.

All the three tests will be open-book type. You are allowed to bring the following items to each of the tests:

1. Pen/pencil/eraser/ruler/paper.
2. A non-graphing calculator. (Cellular phones, PDAs, etc. will NOT be allowed in place of calculators.)
3. Paper copies of the textbooks (PB and JPH).
4. Blank sheets of scrap paper.

There will be 8 (eight) homeworks. Each homework assignment will have two sections, a "common" to all section, and a "distance" section that is only meant for the distance students. In other words, distance students will be graded on all problems, while the in campus students will be graded on only the "common" section.

Letter grade scale (tentative): A: > 80, A-: $75 - 80$, B+: $70 - 75$, B: $65 - 70$, B-: $60 - 65$, C+:$55 - 60$, C: $50 - 55$, C-: $45 - 50$, D: $40 - 45$, E:< 40.

More information on UF grading policy may be found at: `https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx`

Textbook:
The following books are required textbooks for this course.

1. *An Introduction to Feedback Control* by Prabir Barooah (for Part A). A pdf copy of the book will be made available through e-learning. *note:* An old version of this textbook is available in Amazon. Don't buy that version; the one we will use has been updated recently.
2. *Linear System Theory and Design* by João P. Hespanha, Princeton University Press, (for Part B). This book has a second edition, but for this course either edition is fine.

Communication policy (especially email) Only two forms of communication with the instructor and the TA are allowed: face to face interaction or an electronic messages through e-learning. Communication through email is not allowed.
This policy applies to distance students as well. Since face to face interaction is not possible with distance students, audio/video conferencing services - such as skype - may be used after discussing with the instructor/TA through e-learning message(s).

Make up exams etc.
No make-ups will be given for reasons other than medical emergencies or University of Florida business. The latter includes a college athlete having to miss a test due to his/her required participation in a college athletics program, but does not include a student going to watch a football game.
If you have to miss an exam because of UF business, you must see the instructor and make arrangements *at least one week ahead* of the test date.
If you have to miss an exam because of a medical emergency, you must communicate to the instructor that you are facing a medical emergency *before the time the test is scheduled to start.* In case of a medical emergency, you must provide written evidence of the said emergency within five business days

of the scheduled test date for you to qualify for a make up.

Computers/Software
MATLAB©- along with the Control Systems Toolbox - is required to solve many of the home work problems, and will be essential for the final test. You may want to purchase the student version of MATLAB©, which contains the control systems toolbox. Another option is to use UFapps.

Other possibilities for computational software are GNU Octave and Scilab, both of which are free and MATLAB©-like. Yet another possibility is to write programs in python, which has good libraries for scientific computing, including solving ODE. Of course, you can also use C, C++ or Fortran.

Students with Disabilities
The University of Florida provides high-quality services to students with disabilities, and we encourage you to take advantage of them. Students with disabilities needing academic accommodations should 1) Register with and provide documentation to Disability Resources (392-1261), and 2) Bring a letter to the instructor from this office indicating that you need academic accommodations. Please do this as soon as possible, preferably within the first week of class.

Academic Integrity
All students admitted to the University of Florida have signed a statement of academic honesty committing themselves to be honest in all academic work and understanding that failure to comply with this commitment will result in disciplinary action. Academic honesty is therefore taken quite seriously in this class.
No collaboration of any sort is allowed in the take home exams. I highly recommend discussing the home work problems with your colleagues, especially after you have you have spent some time attempting them yourself.

Changes to syllabus policy
Modifications to this syllabus may be made during the semester. Any changes to the syllabus will be announced in class. Such changes may not be posted as announcements in e learning. It's your jib to keep up with the in-class lectures and be cognizant of any changes announced in class.

UF Counseling Services
Resources are available on-campus for students having personal problems or lacking clear career and academic goals. The resources include:

- UF Counseling & Wellness Center, 3190 Radio Rd, 392-1575, psychological and psychiatric services
- Career Resource Center, Reitz Union, 392-1601, career and job search services.

Software Use
All faculty, staff and student of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.