EML 5311 - Spring 2021
Control System Theory

Instructor: Dr. Prabir Barooah
Office: MAE-B 324
E-mail: .... (see policy below).

Class date/time: MWF, period 5 (11:45 am - 12:35 pm);
Class location: online
Office Hours: MWF 5:00 pm - (HLIT)

Lecture format Since this class is being held in an on-line only fashion, lectures will mostly be asynchronous (pre-recorded videos). If a lecture needs to be held in a synchronous manner, I'll send an annoncement via canvas ahead of time. All synchronous lectures (and office hours) will be held via zoom.

Office hours Office hours are really important in this course since the lectures focus on the theory. Office hours are your opportunity to discuss homework problems, where you will need to apply the theory. Because office hours will be via zoom, please join the meeting soon after the scheduled start time. If no one joins after 5 minutes of the start time, I'll end the meeting. If you cannot attend at the scheduled time, message me in canvas and I'll set up an alternate meeting.

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

Teaching Assistant
Kendall Parker
TA office location: N/A (No in person interaction is possible due to COVID).
TA office hours: No fixed office hours; please contact her via Canvas and set up an appointment.

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 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 and Fourier 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. *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.

2. *Linear systems*: LTI and LTV systems, Lyapunov vs. BIBO stability of LTI systems, eigenvalues and Lyapunov equation.

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

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

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

6. *Control of nonlinear systems using linear controllers*: State-space description of non-linear dynamic systems, simulations in MATLAB©, equilibrium points, linearization around an equilibrium point, linearization around a trajectory, controller implementation for nonlinear plant using its linearization.

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 loop shaping and Nyquist criterion. Part B is expected to be new to all, so no familiarity with this material is expected. Familiarity with MATLAB©and Simulink©is also required, as they will be used extensively.

Evaluation criteria
The course letter grade will based on homeworks (25%), Test 1 (25%), Test 2 (25%), and Project (25%). There is no end-of-semester final test.
The dates for the tests are:

1. Test 1: February 24 (Wed), Time: 6 - 9 pm, location: online
2. Test 2: April 15 (Thu), Time: 6-9 pm, location: online

The dates and times and durations are subject to change. Any changes will be announced via canvas.

You are allowed to use following items to each of the tests:

1. Pen/pencil/eraser/ruler/paper. And your phone or a scanner to convert your work written on paper to pdf.
2. A computer or tablet if you want to do your work directly on the computer/tablet, making it easier to convert to pdf for submission.
3. Matlab/Simulink.
4. Paper/electronic copies of the textbooks (PB and JPH).
5. Blank sheets of scrap paper.

Because of the online format, you will have access to the Internet, but you are not allowed to use the Internet to seek help in answering the questions. If you need help with MATLAB©, use the `helpwin` command in MATLAB©.
There will be 8 (eight) homeworks. Since this course has only TA, grading all homework problems is not possible. About a quarter of the homework problems, selected at random, will be graded in detail. Let's call the score a student gets in that portion x. For the rest of the problems that are not graded throughly, a score y will be assigned on the effort expended by the student in answering the questions. The student's score in that homework will be then $0.5 * (x + y)$.
Among the 8 homework assignments, some assignments will have more weight than other ones since they require more effort. The max possible score for a homework assignment will be specified on the assignment and the relative weight of that assignment (as a fraction of the 25% course grade that all homework assignments account for) will be proportional to the max score.

The final project will be released on April 16 (Fri) midnight. The submission due date is Monday, April 26th.

Submissions of all assignments: homeworks, tests and project, will be through canvas. Only .pdf files are allowed for tests. For homeworks, .pdf files and occasionally, matlab (.m, .p and .mat) and simulink (.slx) files will have to be submitted. Project submission will be similar: you will have to submit a report in .pdf format and additional matlab (.m, .p and .mat) and simulink (.slx) files. *No other file formats other than what is described in the assignment instructions will be accepted.*

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`

COVID related special announcements There is no spring break this semester. Instead, Thursday, February 25 and Wednesday, March 24, are designated as Spring Recharge Days. There will be no classes or office hours on March 24.

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 is available through canvas, under Files > Resources > Textbook. *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.

A word of caution: the second textbook (JPH) is a true graduate level textbook while the first one (PB) is meant for undergraduates. Also, we will be using bits and parts of the second textbook that are scattered over it. A combination of these two factors may make the second textbook appear harder to follow.

Communication policy (especially email) Please send me messages through e-learning if you need to contact me, or talk to me directly (that is, via zoom) in my office hours. I get an enormous number of emails, so if you email me it is very likely to get lost in the heap.

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.

In-person requirement for first year international students If you are a first year International student (meaning you were admitted in F20 and S21) who is physically present in the U.S, you must participate in an in-campus activity, specifically, a quiz that will be conducted in a campus building. If you believe you belong to this category, please first verify that it is indeed so by contacting Karen Ehlers at the MAE department. Please contact me after you do so and we will decide on a time and location for the quiz. All other students: please ignore this paragraph.

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.
Important: I am reluctant to use privacy violating tools such as Honorlock to conduct tests. That is why I am making all tests take home. This requires that you take academic integrity extremely seriously.

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.