# ECE4540/ECE5540
# DIGITAL CONTROL SYSTEMS

## Spring 2017

Theory and application of classical and modern discrete-time control systems. Analysis and design of discrete-time and hybrid control using $z$-transforms, root locus, frequency domain and state variable compensation techniques. On-line implementation by digital computers will be studied. ***Prer., ECE4510.***

**Instructor:** Dr. Gregory Plett **Office:** EN–290 **Phone:** 255–3468 **email:** gplett@uccs.edu
**Course web-page:** `http://mocha-java.uccs.edu/`

**Office Hours:** By appointment.

**Text:** G.F. Franklin, J.D. Powell, M. Workman, *Digital Control of Dynamic Systems*, third edition, Addison Wesley, 1998.
**Optional Text:** B. Widrow and E. Walach, *Adaptive Inverse Control*, Wiley Reprint Edition, 2007.

**Optional Software:** "MATLAB and Simulink Student Suite," available from MathWorks (full windows version is running on UCCS computer-lab machines.)

**ECE4540 Evaluation:**
1) Five graded homework mini-projects, including laboratory component, 100% total.

**ECE5540 Evaluation:**
1) Five graded homework mini-projects, including laboratory component, 80% total.
2) Final project, 20%.

**Grading:** 90–100=$A^-$ to $A$; 80–89=$B^-$ to $B^+$; 70–79=$C^-$ to $C^+$; 60–69=$D^-$ to $D^+$; 0–59=$F$.

| Topics | Text | Est. "Weeks" |
|---|---|---|
| 1. Introduction to digital control. | Chs. 1, 2 | 1.0 |
| 2. Emulation of analog controllers. | Chs. 3–6 | 2.5 |
| Lab day. | — | 1.0 |
| 3. Sampling and reconstruction. | Ch. 5 | 2.0 |
| 4. Stability analysis techniques. | — | 1.0 |
| 5. Digital controller design. | Ch. 7 | 2.5 |
| 6. Digital filter structures and quantization effects. | Ch. 10 | 2.0 |
| 7. Adaptive inverse control. | — | 3.0 |

*Work Load:* This is an aggressive course requiring weekly homework assignments. Expect to spend six to nine hours per week outside of class reading the textbook and completing homework assignments. This is in accord with UCCS policy relating credit hours for a lecture course to student workload. Some students will find that more time is required, while others will find that less time is required.

*Homework Policy #1:* Homework will be collected at the beginning of class on the assigned date. Homework turned in after the class period will be penalized 10%. Homework turned in after the due date will be penalized an additional 25% per day unless previous arrangements have been made with the instructor. Examinations will be based on the homework problems and the material covered in class. It is to your advantage to understand the fundamental concepts that are demonstrated in the homework problems. It will be difficult to earn higher than a "C" without performing well on the homework assignments.

*Homework Policy #2:* Your coursework (homework/project/exams) is expected to be a bona-fide individual effort. Copying homework, project or exam solutions from another student or other source is CHEATING and will not be tolerated. You may (and are encouraged to) discuss homework/project problems with other students, but only to the extent that you would discuss them with the instructor. Don't ask another student a question that you would not expect the instructor to answer. Most of us know when we are compromising our integrity. If you are in doubt, ask first.

*Homework Policy #3:* Part of your engineering education involves learning how to communicate technical information to others. Basic standards of neatness and clarity are essential to this process of communication. Your process of solving a problem must be presented in a logical sequence. Consider your assignments to represent your performance as an engineer. Do not submit scrap paper, and do not submit paper containing scratched out notes. Graphs are to be titled and axes are to be labeled (with correct units). The above standards of clarity and neatness also apply to your work on exams.

*Homework Format Rules:* Points will be deducted for failure to comply with the following rules:

1. Use 8 1/2 by 11 paper (engineering paper is good).
2. Write on one side of the paper only.
3. Enclose your final answer to each problem in a box so that it may be clearly identified.
4. Write name and date and homework set number in the right corner.
5. Staple in the upper left corner. Use only one staple!
6. Be sure to write in pencil. Do not use ink to complete your homework assignments.

*Attendance:* Attendance is your responsibility. Class lectures will cover a significant amount of material. Some will not be in the text or may be explained differently. It is to your advantage to take notes, ask questions, and to fully participate in the classroom experience.

*Missed Exams:* Missed exams will count as ZERO without a physician's documentation of an illness, or other appropriate documentation of an emergency beyond your control and requiring your absence.

*Drop Date:* This course complies with the UCCS campus rules for drop date.

*Caution:* Intentional misuse of laboratory equipment will not be tolerated and may result in criminal charges or other discipline.

*The Course Reader:* These notes have been entered using LyX, and typeset with LaTeX2$_\varepsilon$ on a Pentium-II class computer running the Linux operating system. All diagrams have been created using either xfig or Matlab.
Most of these notes are original to me, but several sections have been adapted from lectures given by Dr. Jonathan How at Stanford University.

## Course Objectives

The following are objectives for each unit of the course reader. The student should be able to:

**Unit 1:** Introduction to digital control (review)

- Find transfer functions from differential equations.
- Find Laplace transforms of signals.
- Predict (qualitatively) dynamic response versus pole locations.
- Determine $s$-plane pole locations to meet transient-response specs.
- Determine steady-state error of a system to step/ramp/... inputs.
- Sketch root-locus, Bode and Nyquist plots.

**Unit 2:** Emulation of Analog Controllers

- Given $G(s)$ (first or second order), find discrete-time difference equation to approximate behavior using:
  - Forward and backward rectangular rules.
- Write efficient computer pseudo-code to implement a difference equation.
- Compute $z$-transform of a sequence (with ROC) from the $z$-transform definition.
- Use $z$-transform properties to find a $z$-transform using theorems and known transforms.
  - Including: The two delay theorems, multiplication by cos/sin/...
- Compute transfer function of a difference equation.
- Find inverse $z$-transform by partial-fraction expansion.
- Locate poles in $z$-plane for given time-domain specifications.
- Given $G(s)$ (first or second order), find $G(z)$ to emulate using frequency-domain conversions:
  - Forward and backward rectangular rules;
  - Bilinear and pre-warped bilinear rules;
  - Pole-zero matching;
  - Zero-order-hold equivalent.

**Unit 3:** Sampling and Reconstruction

- Find $X^*(s)$ for a sampled signal.
- Plot the aliased spectra of a signal (given spectra of signal at input to sampler).
- Convert continuous-time plant $G_p(s)$ plus ZOH to $G(z)$.
- Find starred Laplace transform of hybrid continuous- and discrete-time system.
- Find loop transfer function and closed-loop transfer function of system with controller, plant and sensor dynamics, in $s^*$ and $z$ domains.
- Find modified $z$ transform of system with pure time delay.

**Unit 4:** Stability Analysis Techniques

- Convert $T(z)$ to $T(w)$ via bilinear transform.
- Determine stability of $T(w)$ using Routh-Hurwitz method.
- Determine stability of $T(z)$ using Jury method.
- Determine stability of system using root-locus plot.
- Determine stability of system using Nyquist plot.
- Determine stability of system using Bode plot.

**Unit 5:** Digital Controller Design

- Apply time-domain specifications to find acceptable pole locations for $T(z)$.
- Phase lead and lag design using Bode plot techniques.
- Phase lead and lag design using root-locus plot techniques.
- Be able to implement numeric PID design.
- Design a controller using Ragazzini's method.

**Unit 6:** Digital Filter Structures and Quantization Effects

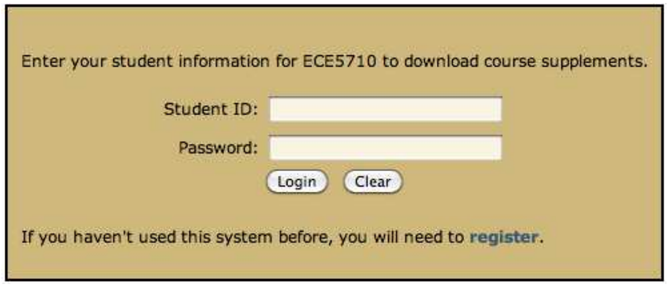
- Write a transfer function in the direct, cascade, coupled, and parallel forms (both I and II for each).
- Know the properties of direct, cascade, coupled, and parallel forms.
- Determine noise power at a point in a circuit due to quantizer(s).
- Determine how to scale signals in a network to avoid overflow (both BIBO and worst-case scenarios).
- Use dither to eliminate or mitigate limit cycles.

**Unit 7:** Adaptive Inverse Control

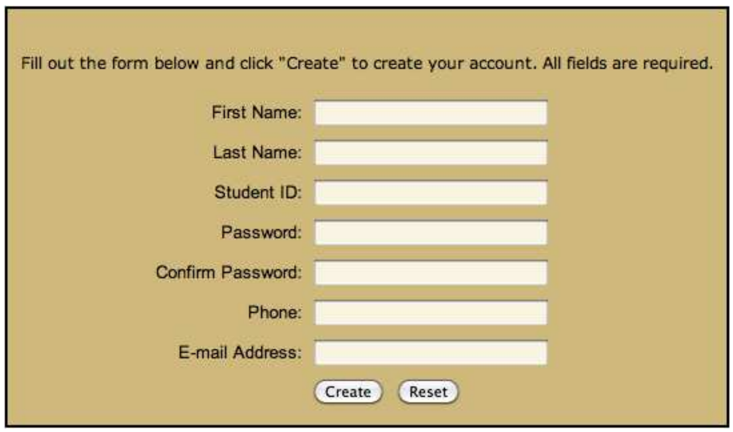
- Implement an adaptive system ID method for SISO linear systems using FIR filters and the LMS algorithm.
- Implement model-reference-based adaptive feedforward control of SISO linear systems using FIR filters and the LMS algorithm.
- Implement disturbance canceling for SISO linear systems using FIR filters and the LMS algorithm.
- Implement adaptive system ID, model-reference-based adaptive feedforward control, and disturbance canceling for MIMO systems using block FIR filters and the RLS algorithm.

# The EduFile Course Supplement Management System (***EduFile***):

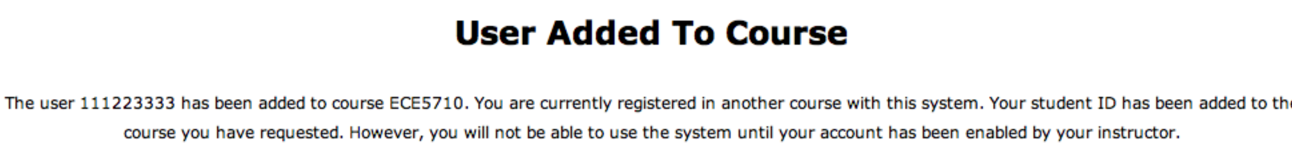
The class homepage is accessed via `http://mocha-java.uccs.edu/`. Click on the [+] sign next to the course name, and then click on the link to access course supplements.
Follow this link, and you will be directed to the log-on screen (for ECE4540/5540):



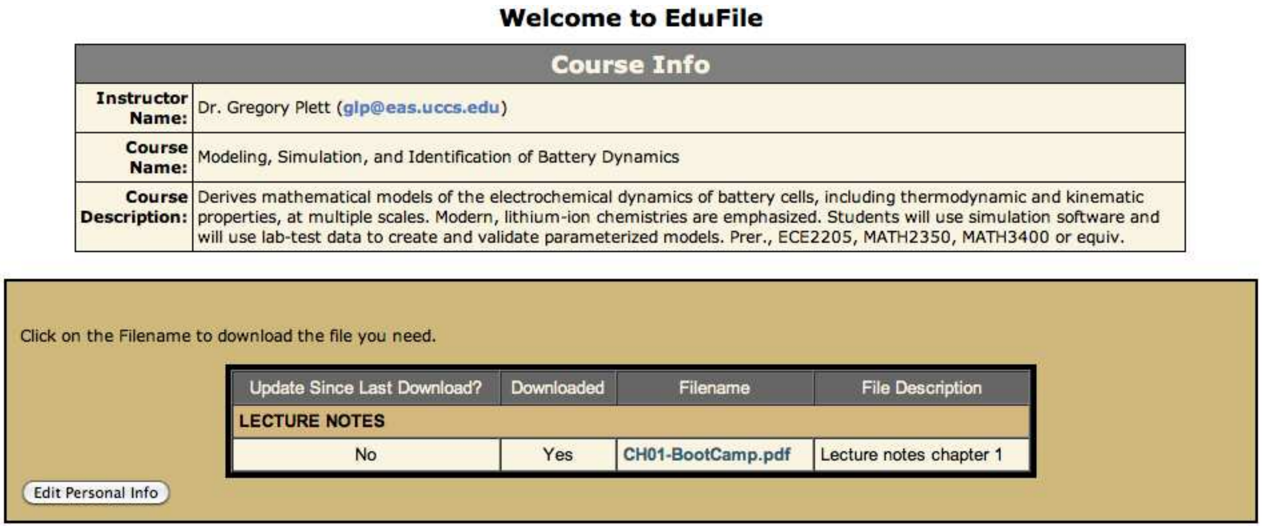

The first time you use the system, click on the word "register". You will be directed to the screen:




Enter the requested information and press "Create". You should see the screen (for 5530):




Note that passwords are case-sensitive!
You will not immediately gain access to course supplements. You will receive email notification when your account is enabled for this course. Only then may you log on using your student ID and password. You will see a screen like this (tailored to ECE4540/5540, of course):




At the top of the page, the course name, course description and instructor are listed. By clicking on the instructor email address, you may send an email message directly from your web browser to the instructor. Below the course description is a listing of supplements that you may download. These are divided into categories (*e.g.*, ANNOUNCEMENTS, CHAPTER 1. . . ) as assigned by the instructor.

In the figure, we see that this student has downloaded CH01-BootCamp.pdf. Furthermore, she is assured that she has the most recent copy of this file since the flag "Update Since Last Download" says "No". However, if the file had been updated since the last time she downloaded it, the flag would have said "Yes," so she would know to retrieve the newer version. Not shown, because it falls at the bottom of the page, is a button allowing the student to modify her personal information (name, password, and so forth).