ENME 605 – Advanced Control Systems, Fall 2015

Department of Mechanical Engineering

Lecture Details

Tuesday and Thursday, 4:00 pm to 5:15 pm
Information Technology and Engineering (ITE), Room 241

Instructor

Name: S. Andrew Gadsden, Ph.D., P.Eng., P.M.P.
Office: ENGR 225C
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Course Objectives

1. Provide a theoretical understanding of advanced linear control systems and strategies, including the principles of digital control.
2. Design, build, simulate, and test control systems and strategies using both MATLAB and Simulink.
3. Work on a controls-based project related to graduate thesis work. If graduate thesis is not controls-related, a relevant project will be assigned.

Textbook(s)

Required: None. Lecture notes will be provided.

References:

1. *Nonlinear Systems (3rd Edition)* by Hassan K. Khalil.
2. *Nonlinear Control* by Hassan K. Khalil.
3. *Modern Control Engineering* by K. Ogata.
4. *Digital Control of Dynamic Systems* by G. F. Franklin et al.
5. *Computer-Controlled Systems* by K. J. Astrom et al.
6. *Applied Nonlinear Control* by J. J. Slotine et al.
7. *Control Systems Engineering* by N. Nise.
8. *Advanced Mechanical Engineering Control Systems* by Gary Bone. Mechanical Engineering 751, McMaster University.

Course Description

This course is intended to reinforce the concepts learned in ENME 403 (Automatic Controls), which is a *pre-requisite* to this course. Sufficient background material will be provided to those who do not have the required *pre-requisite*. The following concepts will be considered:

- Basic principles of control systems engineering
- Modeling of sampled-data systems, sampling rate selection
- Controller design with continuous systems
- Direct digital design
- Design considerations for robust control
- Feedforward control
- State space methods for control and estimation
- Optimal feedback, and long range predictive control
- Adaptive, learning, fuzzy, and variable structure control

Grading Policy

The interim and final course grades will be based on the following approximate grade weights and breakdowns.

Assignments	30%
Midterm Exam (Take-Home)	20%
Project Report and Presentation	50%

Grade Assignment

A	85% to 100%	**C+**	67% to 69.9%
A-	80% to 84.9%	**C**	63% to 66.9%
B+	77% to 79.9%	**C-**	60% to 62.9%
B	73% to 76.9%	**D**	55% to 59.9%
B-	70% to 72.9%	**F**	0% to 54.9%

Policies and Procedures

i) Assignments must be submitted individually (online), however students are encouraged to work together to solve problems.
ii) Assignments are due before lecture on the day that they are due as per the schedule. The work is due on time. No late work will be accepted (must be submitted before 4:00 pm as per the schedule). Late work will be assigned a grade of zero.
iii) The class midterm is a take-home examination. Each student must complete the examination individually, and not collaborate with others.
iv) Follow the latest project report guidelines on Blackboard. Content is most important, however grammar, spelling, and so forth, are also considered.

Collaboration Policy

Assignments may be collaborative, however must be submitted individually. The midterm examination and project are to be done individually.

Academic Integrity

By enrolling in this course, each student assumes full responsibility as a participant in UMBC's scholarly community in which everyone's academic work and behavior are held to the highest standards of honesty. Cheating, fabrication, plagiarism, and helping others to commit these acts are all forms of academic dishonesty. Academic misconduct could result in disciplinary action that may include, but is not limited to, a grade of zero on the particular work, a grade of F in the class, suspension, or dismissal. Please refer to the full student academic conduct policy for more information.

Syllabus Note

Please note that this course syllabus is subject to change. The most recent version is available on the course website (Blackboard).

Fall 2015 Class Schedule

Week	Lecture Day	Topic/Event	Deliverable*
8/24	Tuesday	No Class	
	Thursday	1 – Introduction to course and material review	
8/31	Tuesday	2 – Modeling of sampled-data systems (1 of 2)	
	Thursday	2 – Modeling of sampled-data systems (2 of 2)	
9/7	Tuesday	3 – Sampling rate selection	
	Thursday	4 – Controller design with continuous systems (1 of 2)	
9/14	Tuesday	4 – Controller design with continuous systems (2 of 2)	**Assignment #1**
	Thursday	5 – Direct digital design	
9/21	Tuesday	6 – Design considerations for robust control	
	Thursday	7 – Feedforward control	
9/28	Tuesday	8 – State space methods for control and estimation	**Assignment #2**
	Thursday	9 – Optimal feedback control and optimal estimation	
10/5	Tuesday	10 – Long range predictive control	
	Thursday	No Class	
10/12	Tuesday	11 – Adaptive control	**Assignment #3**
	Thursday	12 – Dealing with actuator constraints	
10/19	Tuesday	13 – Learning control	
	Thursday	14 – Fuzzy control	
10/26	Tuesday	15 – Variable structure control (1 of 2)	**Assignment #4**
	Thursday	15 – Variable structure control (2 of 2)	
11/2	Tuesday	Discussions	
	Thursday	Discussions	
11/9	Tuesday	Discussions	**Midterm Exam**
	Thursday	Discussions	
11/16	Tuesday	Discussions	
	Thursday	Discussions	
11/23	Tuesday	Discussions	
	Thursday	No Class (Thanksgiving)	Turkey
11/30	Tuesday	Presentations	**Presentations**
	Thursday	Presentations	**Presentations**
12/7	Tuesday	Presentations (if needed), and course feedback	**Reports**
	Thursday	No Class	

***Notes:** All deliverables are due prior to the stat of class, and must be submitted electronically.

Outline of Course Content

1. Introduction to digital control **(1 day)**
   a. Overview
   b. Objectives
   c. Control system specifications
   d. Distinct control vs digital control
2. Modeling of sampled-data systems **(2 days)**
   a. The z-transform and sampled-data systems
   b. Properties and inverse of z-transform
   c. Discrete models of sampled data systems
   d. System identification
   e. Other modeling approaches
3. Sampling rate selection **(1 day)**
   a. Sampling theorem and aliasing
   b. Selection based on smoothness of input and output
   c. Disturbance rejection
   d. Stability
   e. Hardware and software limitations
4. Controller design using emulation of continuous systems **(2 days)**
   a. Comparison of emulation methods: numerical integration, pole-zero mapping, hold equivalence
   b. Discrete PID control and Zeigler-Nichols tuning method
   c. Continuous controller design using Bode plots
5. Direct digital design **(1 day)**
   a. Introduction to direct design
   b. Conversion of time domain specifications to the z-plane
   c. Z-plane root locus
   d. Direct digital design method of Ragazzini
6. Design considerations for robust control **(1 day)**
   a. Overview
   b. Sensitivity to modeling errors
   c. Disturbance rejection
   d. Relative stability
   e. Effect of sensor noise
   f. Other methods to analyze robustness
7. Feedforward control **(1 day)**
   a. Introduction
   b. Sensitivity to modeling errors
   c. Design methodology

8. State space methods for control and estimation **(1 day)**
    a. Introduction
    b. Continuous time state-space plant model
    c. Discrete time state-space model
    d. Design of state space pole placement control
    e. Estimator design
9. Optimal feedback control and optimal estimation **(1 day)**
    a. Time varying optimal feedback control
    b. LQR steady state optimal feedback control
    c. LQG control
    d. Optimal estimation
10. Long range predictive control (LRPC) **(1 day)**
    a. Overview
    b. Tuning
    c. Advantages and disadvantages
11. Adaptive control **(1 day)**
    a. Introduction
    b. Gain scheduling
    c. Model-reference adaptive systems (MRAS)
    d. Self-tuning regulators (STRs)
    e. Recursive least-squares (RLS) estimation with exponential forgetting
12. Dealing with actuator constraints **(1 day)**
    a. Introduction
    b. Modifying a continuous-time linear controller for anti-windup
    c. Other anti-windup methods
    d. State-variable feedback and anti-windup
    e. Other constraints
13. Learning control **(1 day)**
    a. Iterative learning control (ILC)
    b. ILC algorithm
    c. Convergence analysis
    d. Linear discrete time SISO ILC
    e. Conclusions on ILC
14. Fuzzy control **(1 day)**
    a. Fuzzy sets
    b. Fuzzy control
    c. Fuzzy rules
15. Variable structure control **(2 days)**
    a. Introduction
    b. Mathematical background
    c. Basic theory of sliding mode control (SMC)
    d. Equivalent control method
    e. Implementation issues