Course Syllabus
ECE/MAE 7750 - Distributed Control Systems
Spring 2005

Last/First offered: Spring 2002.
Instructor: YangQuan Chen, Center for Self-Organizing and Intelligent Systems
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EL 216, T: (435)797-0148, E: yqchen@ece.usu.edu
Class Schedule: MW 11:00 AM to 12:15 PM (tbd)
Class Venue: Engr 206 (Lectures) and **EL112 Control Laboratory** (Projects).
Office Hours: MW 12:15-13:30 or by appointment. Try to formulate your question in written form first (your question may no longer be a question during your write-up!)

Course website: http://mechatronics.ece.usu.edu/ece7750/
Text: No official textbook. Handouts will be given during the class.

References:
Books:
[1]. William S. Levine (Editor), *The Control Handbook* (Electrical Engineering Handbook Series), CRC Press, March 1996 (1566 pages!)
[2]. R. F. Curtain and H. J. Zwart, *An Introduction to Infinite-Dimensional Linear Systems Theory*, Springer-Verlag, 1995.
[3]. M. P. Lukas, *Distributed Control Systems: Their Evaluation and Design*. Van Nostrand Reinhold Company. 1986. (TS 156.8.L85)
[4]. Alan Jeffrey, *Advanced Engineering Mathematics*. Academic Press. 2002. Chapter 18. "*Partial Differential Equations*". (pp. 925-1042)
[5]. P. M. Chirlan, Signal, Systems, and the Computer. Weber Systems, Inc. 1986. (Chapter 10. "*Distributed Systems*" and Sec. 3.12. "*Evaluating inverse Laplace transformation when F(s) has branch points*")
[6]. Podlubny, I.: ***Fractional Differential Equations.*** *An Introduction to Fractional Derivatives, Fractional Differential Equations, to Methods of their Solution and some of their Applications.* Academic Press, San Diego - Boston - New York - London - Tokyo - Toronto, 1999, 368 pages, ISBN 0-12-558840-2.

Control Journals:
- SIAM J. of Optimization and Control
- IEEE Transactions on Automatic Control
- IEEE Transactions on Control Systems Technology
- IEEE Control Systems
- Control Engineering Practice
- Automatica
- Mechatronics
- IEEE/ASME Trans. on Mechatronics

Conferences:

- IEEE CDC (Conference on Decision and Control)
- AACC ACC (American Control Conference)
- IFAC World Congress

Online papers/books:

- http://www.ieeexplore.ieee.org (since 1998 to present, all IEEE paper)
- USU library – online journals
- For more online research resource, check links from the instructor's personal web:

http://www.csois.usu.edu/people/yqchen/students/

- http://www.engnetbase.com/ (many free handbooks)
- www.arxiv.org
- citeseer

Prerequisites: Undergraduate control systems and graduate linear multivariable systems, or subject to the Instructor's approval. It is advantageous to have one or more subject knowledge backgrounds in Real Functional Analysis, Networking Techniques, Industrial Control, Fluid Mechanics etc.

Course Requirements:

Projects	30 points
Assignments	30 points
Focus Independent Studies and Presentations:	40 points
There is no Mid-term Exam and Final Exam.	

Notes:

1. This is a **research-type** course at 7000 level with mixed lectures from the Instructor and presentations by the students of the class.
2. The course will follow the topics outline below.
3. There will be 3 projects and 6 assignments. The due time is plus or minus 0.5 week around the due date designated. Projects can be completed in team. However, for assignments, independent work is required.
4. FISP (focused independent study and presentation) will be assigned to each student with different topics. This FISP includes a survey report on the chosen specific topic or a specific analysis/design technique in distributed control systems. There will be two FISP topics for each student. The topics can be proposed by the students upon instructor's approval.
5. Computer simulations will be necessary for some homework/FISP problems. Matlab/Simulink is the preferred computing environment for these simulations. In some projects, C++ programming is required.

Course Description:

This course is meant to prepare the students to better fit in the "*information and nano age*" or "*nano-bio-info age*" where the distributed dynamic systems modeling and control are ubiquitous.

This research type course is a comprehensive exposition of the state-of-the-art in distributed control systems including four major parts:

- (1) networked control system (NCS),
- (2) wireless sensor networks (WSN),
- (3) distributed parameter systems (DPS), and
- (4) industrial DCS (iDCS) and large scaled system optimization (LSS).

Note that each part listed above could be an independent graduate level course. This course is with an emphasis on the broad coverage. The depth rests at the students' FISP topics, projects and assignments.

In Part (1), we will focus on control systems involving (or via) networks. In addition to introducing various networking components in NCS, we shall focus on the stability analysis, controller design and performance evaluation of NCS with various types of network-induced delays. In Part (2), we will focus on the sensor networks in general and wireless sensor networks and actuator networks in particular. In Part (3), the basic concepts in analysis and control of systems described by partial differential equations (PDE) will be covered including the typical PDEs and their related physical processes, strong semi-group theory, controllability and observability, boundary control problems, and Laplace transformation approach via fractional order calculus. For Part (4), we will cover the basic principles in iDCS configuration, evaluation and application. The current trend in iDCS will be surveyed. In higher level, the optimization of LSS is an important aspect in real world such as "enterprise control".

Outline of Topics:

Seeing the big picture – Introduction to "Distributed Control Systems"

- Motivations, ubiquitous, benefits and challenges.
- Why it is the right time to study "Distributed Control Systems".

Network Controlled Systems (NCS)

- NCS using existing networking facilities (e.g. internet)
- Dedicated networking protocol design for NCS for better control system performance
- System control ideas for better networking performance.
- Network induced delay(s): characterization, stability analysis
- Control system design techniques to compensate delay(s).

Wireless Sensor Networks (WSN)

- Overview of sensor networks
- MAS-net (mobile actuator and sensor networks)
- Mote-based WSN – a case study
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Distributed Parameter Systems

- Introduction to PDEs and typical physical processes. PDE MATLAB Toolbox.
- Review of functional analysis, C0-semigroup operator theory.
- Controllability and observability of infinite dimensional linear systems
- Stability and wellposedness.
- Boundary control of DPS
- Fractional order calculus and fractional order control
- Laplace transformation approach for DPS via fractional order calculus,
- Special DPS's: spatial-invariant systems and CD (cross-directional) control of paper machines.

Industrial DCS and Large Scale Systems Optimization

- From PLC to DCS – the factory automation via ICCS (integrated communication and control systems)
- Typical iDCS configurations, evaluation and application domains. Current status and future trend of iDCS.
- LSS optimization – basic theory. Connections to enterprise control and decision support systems and operational research.

Detailed Schedule (subject to minor changes)

wk	#	Date	Topic	Handouts/project/ Assignment	Speaker/ Instructor
1	1	1/10	Big picture on "Distributed Control Systems". Review of classical control and linear multivariable control.	Notes. Papers	Dr. Chen
1	2	1/12	Review of Basic Networking and NCS overview	Papers, Notes. Project #1: Understanding and Constructing an NCS (tele-control of CSOIS smart wheel rig)	Dr. Ma Dr. Chen
1		1/14	Demo (Bharath's slides) and plan of Project#1. Class meeting EL216		
2	3	1/17	Industrial Protocols	FISP #1 (IEEE Trans. AC Special Issue) assignments / Papers, Notes.	Dr. Chen
2	4	1/19	Time-delay Compensation	Notes Assignment#1. Delay compensation	Dr. Chen
2		1/21			
3	5	1/24	FISP1.1 FISP1.2 FISP1.3	FISP #1 (IEEE Trans. AC Special Issue, Control Systems Magazine)	
3	6	1/26	FISP1.4 FISP1.5 FISP1.6	FISP #1 (IEEE Trans. AC Special Issue, Control Systems Magazine)	
3		1/28			
4	7	1/31	FISP1.7 FISP1.8 Intermittent ILC (Hyosung)	FISP #1 (IEEE Trans. AC Special Issue, Control Systems Magazine)	
4	8	2/2	WSN overview (motivations, applications, literature reviews, research issues)	Notes, papers.	Zhen Song
4		2/4	MAS-net demo (CSOIS Blue Room) – Zhen Song and Zhongmin		
5	9	2/7	MAS-net (MASmote, Intel Mote details, TonyOS, S-MAC)	Project #2. Experience with Mote based wireless sensor networks (basic setup and programming)	Zhongmin
5	10	2/9	MAS-net (MASmote, Intel Mote details, TonyOS, S-MAC)		Zhongmin
5		2/11	Project #2.		
6	11	2/14	FISP2.1 FISP2.2 FISP2.3	FISP #2	
6	12	2/16	FISP2.4 FISP2.5 FISP2.6	FISP #2	Chen

6		2/18			
7	13	2/21	FISP2.7 FISP2.8 FISP2.9 Dr. Chen	FISP #2	
7	14	2/23	Introduction on PDEs, classification and typical physical processes.	PDE chapter in [4].	
7		2/25			
8	15	2/28	Method of Characteristics for the first order PDEs, some examples in physical processes. Solution via MATLAB PDE Toolbox.	Assignment #2. Solving simple PDEs both manually and by Matlab PDE Toolbox	
8	16	3/2	PDE in Electrical Engineering – transmission line example.	Notes Assignment #3. Time domain response of a transmission line and impedance matching computation	Dr. Chen
8		3/4			
9	15	3/7	Review of functional analysis, C0-semigroup operator theory, generating operator, evolutional equations	Notes	Dr. Chen
9	16	3/9	Controllability and observability of infinite-dimensional linear system	Notes	Dr. Chen
9		3/11			
10	17	3/14	**Spring Break. No class.**		
10	18	3/16			
10		3/18			
11	19	3/21	Introduction to fractional order calculus and its applications in control and signal processing.	Notes	Dr. Chen
11	20	3/23	Laplace transformation techniques for PDE solution.	Notes Assignment #4. Solving PDE Using Integral Transformation	Dr. Chen
11		3/25			
12	21	3/28	Boundary control Hybrid symbolic and numerical simulation method	Notes Assignment #5. Optimal boundary controller simulation	Dr. Chen
12	22	3/30	Controller design for special types of PDS's: spatially-invariant system and CD control via 2D loop-shaping – a brief introduction	Notes	Dr. Chen
12		4/1			
13	23	4/4	Mobile sensor scheduling for optimal identification of distributed parameter systems.	Notes, Dr. Ucinski's book.	Dr. Chen & Jinsong

13	24	4/6	MAS-Diff2D, MAS-Diff2D, MAS-Wave1D, MAS-Wave2D. Motivations, concepts, demos and further research issues	Notes Project#3, Optimal sensor location for distributed parameter system identification	Dr. Chen & Jinsong
13		4/8			
14	25	4/11	Platooning control in intelligent highway systems, String/mesh stability	Notes	Dr. Chen & Zhongmin
14	26	4/13	A survey of iDCS: current status and future trend. Introduction to a typical iDCS.	Notes	Zhen Song
14		4/15			
15	27	4/18	○ Biological networks. ○ Introduction of large scale system (LSS): centralized vs. decentralized and lumped vs. distributed.	Notes	Dr. Chen
15	28	4/20	Optimization techniques for steady-state LSS's. Introducing TOMLAB.	Notes	Dr. Chen
15		4/22			
16	29	4/25	Complexity, robustness, power law, and reliable control.	Notes	Dr. Chen
16	30	4/27	Topics in enterprise control	Notes	Dr. Chen
16		4/29	**Exit interview.**		

Notes for student presenters:

1. You need to spend sufficient amount of time in the given topic in reading papers, searching internet resources, preparing your survey report and presentation slides in MS PowerPoint or in PDFLaTeX.
2. Each presentation is 20 min. plus a 5-10 min. Q/A session.
3. You are responsible to prepare properly selected handouts (copies will be made by the Instructor) for the class to complement your presentation.

- **Project #1: Understanding and Constructing an NCS (tele-control of CSOIS smart wheel rig)**
- **Project #2. Experience with Mote based wireless sensor networks (basic setup and programming)**
- **Project#3, Optimal sensor location for distributed parameter system identification**

- **Assignment #1. Delay compensation**
- **Assignment #2. Solving simple PDEs both manually and via Matlab PDE Toolbox**
- **Assignment #3. Time domain response of a transmission line and impedance matching computation**
- **Assignment #4. Solving PDE Using Integral Transformation**
- **Assignment #5. Optimal boundary controller simulation**