

# Course Syllabus

## ECE/MAE 7750 - Distributed Control Systems

### Spring 2002

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**Consulting Advisory Professor:** Professors Kevin L. Moore

**Class Schedule:** Tue.Thu. 11:00 AM to 12:15 PM

**Class Venue:** EL109 (Lectures) and EL112 Control Laboratory (Projects).

**Office Hours:** T.Th. 4:15 PM to 5:30 PM or by appointment. Try to formulate your question in written form first (your question may no longer be a question during your write-up!)

<http://www.usu.edu/registra/spring2002/courses/ECE.html>

18610 ECE 7750 001 DISTRIB CONTROL SYS 3.0 \_T\_R\_ 7:30- 8:45 \$20.00 Moore K EL 109

**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.

Journals:

- IEEE Transactions on Automatic Control
- SIAM J. of Optimization and Control
- IEEE Transactions on Control Systems Technology
- IEEE Control Systems.

**Prerequisites:** Undergraduate control systems and graduate linear multivariable systems. 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	20 points
Focus Independent Studies and Presentations:	50 points

**There is no Mid-term Exam and Final Exam.**

**Notes:**

1. This is a **research-type** course at 7000 level with a mixed lectures from the Instructor and the Consulting Advisory Professor and presentations by the students of the class.
2. The course will follow the topics outline below.
3. There will be 3 projects and 4 assignments. The due time is plus or minus a 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*” where the distributed systems control is ubiquitous.

This research type course is a comprehensive exposition of the state-of-the-art in distributed control systems including three major parts: (1) networked control system (NCS), (2) distributed parameter systems (DPS), and (3) industrial DCS (iDCS) and large scaled system optimization (LSS), with each part can be an independent graduate course. 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), 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 (3), 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.

## **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 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).

### **Distributed Parameter Systems**

- Introduction to PDEs and typical physical processes. PDE MATLAB Toolbox.
- Review of functional analysis,  $C_0$ -semigroup operator theory.
- Controllability and observability of infinite dimensional linear systems
- Stability and wellposedness.
- Boundary control of DPS
- 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	1/8	Big picture on “Distributed Control Systems”	Notes. Papers	Moore
1	2	1/10	NCS overview	Papers, Notes. Project #1: Constructing NCS	Chen
2	3	1/15	Meet to plan network control setup in Project #1.	Project #1	Class meeting
2	4	1/17	No class. Meet to plan network control experiments in Project #1.	Project #1	Class meeting
3	5	1/22	Lecture on Stability of NCS (1)	Notes. Papers.	Moore
3	6	1/24	Lecture on Stability of NCS (2)	Notes. Papers.	Moore
4	7	1/29	Presentation on Industrial Protocols	FISP #1	Lili, Vikas, Zheng
4	8	1/31	Presentation on Time-delay Compensation	FISP #1	Liang, Jared, Kumaresh
5	9	2/5	Presentation and demo on network control experiment	Project #1	All students
5	10	2/7	No class. Meet to plan network delay compensation experiment	Project #2	
6	11	2/12	Introduction on PDEs, classification and typical physical processes.	PDE chapter in [4].	Chen
6	12	2/14	Method of Characteristics for the first order PDEs, some examples in physical processes. Solution via MATLAB PDE Toolbox.	Assignment #1. Solving simple PDEs	Chen
7		2/19	No class. Break for Olympics.		
7		2/21			
8	13	2/26	Presentation and demo on network delay compensation experiment	Project #2	All students
8	14	2/28	PDE in Electrical Engineering – transmission line example.	Notes Assignment #2. Time domain response of a transmission line and impedance matching computation.	Chen
9	15	3/5	Review of functional analysis, $C_0$ -semigroup operator theory, generating operator, evolution equations	Notes	Chen
9	16	3/7	Controllability and observability of infinite-dimensional linear system	Notes	Chen
10	17	3/12	Stability, Stabilizability and Detectability of DPS.	Notes	Chen

10	18	3/14	Boundary Control	Notes Project #3: Boundary control design and simulation of an elastic beam with external disturbance.	Chen
11	19	3/19	Introduction to fractional order calculus and its applications in control and signal processing.	Notes	Chen
11	20	3/21	Laplace transformation techniques for PDE solution.	Notes Assignment #3. Solve heat equation using the Laplace transformation.	Chen
12	21	3/26	A Wiener-Hopf controller design method for a typical PDE system.	Notes	Chen
12	22	3/28	Controller design for special types of PDS's: spatially-invariant system and CD control via 2D loop-shaping – a brief introduction	Notes	Chen
13	23	4/2	Control of flexible link robot using strain feedback. DCS related to Autonomous Formation Flight and Satellites Constellation.	FISP #2	Kumaresh Jingsong
13	24	4/4	Control ideas for better networking performance Temporal-spatial filtering for mobile robot navigation and control.	FISP #2	Vikas Lili
14	25	4/9	Platooning control in intelligent highway systems Controlling liquid sloshing in spacecraft	Chen Fullmer(TBD)	
14	26	4/11	A survey of iDCS: current status and future trend. Introduction to a typical iDCS.	FISP #2	Jared Zhen
15	27	4/16	Introduction of large scaled system: centralized vs. decentralized and lumped vs. distributed.	Notes	Moore
15	28	4/18	Optimization techniques for steady-state LSS's.	Assignment #4, A large scale optimization problem via MATLAB TOMLAB.	Chen
16	29	4/23	Complexity, robustness and reliability.	Notes	Chen
16	30	4/25	Topics in enterprise control	Notes	Chen
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 30 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.