



Introduction to Networked Control Systems



Vijay Gupta

Richard M. Murray

University of Notre Dame California Institute of Technology

HYCON-EECI Graduate School on Control 2009

16-20 March 2009

Goals for the course:

- Review recent applications in control that motivate networked control systems
- Provide an overview of basic tools from communications, computer science and control theory that can be used as a basis for further studies
- Review recent results in distributed estimation and control, packet-based estimation and control, control in presence of quantization and time-delay
- Discuss open research problems and emerging NCS applications

Course Instructors



Vijay Gupta
University of Notre Dame

Education

- B. Tech, IIT Dehli, EE
- MS, PhD, Caltech, EE
- Asst Professor, Notre Dame, EE

Research interests

- networked control systems
- sensor networks
- distributed estimation and detection
- usage-based value of information



Richard M. Murray
California Institute of Technology

Education

- BS, Caltech, EE
- MS, PhD UC Berkeley, EECS
- Professor, Caltech, CDS and BE

Research interests

- networked control systems
- verification of distributed control systems
- bioplausible control design/insect flight
- biological circuit design

Outline of Lectures

	Mon	Tue	Wed	Thu	Fri
9:00	L1: Intro to Networked Control Systems	L5: Distributed Control Systems	L7: Information Theory and Communications	L11: Estimation over Networks	L13: Distributed Protocols and CCL
11:00	L2: Optimization-Based Control	L6: Cooperative Control	L8: Jump Linear Markov Processes	L12: Distributed Estimation and Sensor Fusion	L14: Open Problems and Future Research
12:00	Lunch	Lunch	Lunch	Lunch	Lunch
14:00	L3: Information Patterns		L9: Packet Loss, Delays and Shock Absorbers		
16:00	L4: Graph Theory		L10: Quantization and Bandwidth Limits		

Comments on Style and Approach

NCS is an emerging research area

- Many results are new (in the last 5 years) and haven't yet been standardized
- Integration between different aspects of NCS are a work in progress

NCS is a systems problem

- Successful NCS research requires integration of component technologies
- Lectures will summarize key elements, with selected detail
- Application examples will highlight the many gaps in the theory

Lots of additional material online

- Additional references, web pages, etc are posted on the wiki pages
- Detailed derivations and proofs for most results

NCS: Real-Time Trajectory Generation

[Prev: Alice Follow](#)
[Course Home](#)
[Next: RHC](#)

In this lecture we provide an overview of real-time trajectory generation for nonlinear control systems. Using the concept of differential flatness, we show how to convert the trajectory generation problem from one in optimal control to one of optimization. Efficient numerical methods can then be used to find trajectories that satisfy the system dynamics and constraints, as well as minimizing a cost function. We concentrate on methods for real-time trajectory generation, and in particular the **NTG** software package.

[\[edit\]](#)

Lecture Materials [\[edit\]](#)

- [Lecture: Nonlinear Trajectory Generation](#)

Reading [\[edit\]](#)

- [A New Computational Approach to Real-Time Trajectory Generation for Constrained Mechanical Systems](#) , M. B. Milam, K. Mushambi and R. M. Murray. Conference on Decision and Control, 2000. This is one of the earliest papers on NTG, written by a Caltech PhD student (Milam) and a Caltech undergraduate (Mushambi). This is a good overview paper for the setup that NTG uses.
- [Inversion Based Constrained Trajectory Optimization](#) , N. Petit, M. B. Milam and R. M. Murray. IFAC Symposium on Nonlinear Control Systems Design (NOLCOS), 2001. This paper talks about some of the computational tradeoffs regarding defect (non-flatness) of a system.

Additional Resources [\[edit\]](#)

- [Real-Time Optimal Trajectory Generation for Constrained Dynamical Systems](#) , M. Milam. PhD Thesis, 2003.
- [NTG software](#) , version 2.2a, 2002. This is the last publically released version of NTG.

<http://www.cds.caltech.edu/~murray/wiki/ncs-sp09>