EE 588
Linear-Quadratic Control
Dr. E. Jonckheere
Spring 2010

The purpose of this course is to develop the basic tools and techniques of linear-quadratic optimization in both the control setup (the "LQG" problem) and the estimation setup (the "Kalman-Bucy" filtering problem). The most natural approach to such problems is via modern state-space techniques and, as such, this course can be viewed as a spinoff of EE585, *Linear Systems Theory*. However, linear-quadratic optimization also has such traditional feedback interpretations as disturbance rejection, Bode limitation, phase and gain margins, etc., which were overlooked for a while before I. Horowitz, G. Zames, H. Rosenbrock, and many others reemphasized the importance of traditional control concepts against the then prevailing modern state-space approach. In this course, we will strive to develop jointly the modern and the traditional aspects in some kind of symbiotic theory. If time allows, and depending on students' interests, we might develop a quick introduction to H^∞ design.

Proceeding further, the Linear-Quadratic-Gaussian (LQG) problem will be viewed as an entry into the field of stochastic control. Having been somewhat ignored for many years, stochastic control is currently experiencing a revival, because of many recent applications where the need for a more formal mathematically approach is badly felt. Such applications include Internet control (e.g., congestion notification is fundamentally stochastic and requires the definition of a "stochastic differential equation driven by a Poisson process"), smart grid (where topology faults make the system hybrid/stochastic), and even more recently quantum control (e.g., stochastic decoherence rate). All of these new applications call for a deeper understanding of stochastic processes. In this context, it is fitting to go over the Ito versus Stratonovich stochastic calculus pitfall. Cutting edge application will be chosen among Random Early Detection (RED) in network control, Active Queue Management (AQM), video streaming, the Kushner-Stratonovich equation of quantum control through scheduling of measurements, or the continuous measurement equations in quantum control.

This course somewhat overlaps with EE556, *Stochastic Control*, taught by Dr. Rahul Jain. Both instructors are aware of this and all attempts will be made to avoid undue overlaps.

Prerequisites:

EE482, *"Linear Control Systems,"* and EE585, *"Linear Systems Theory,"* are *recommended preparations* rather than formal prerequisites. Of course, the students will be expected to be familiar with basic feedback theory (stability, gain/phase margins, Bode diagrams, etc.) and state space theory (state space equation, controllability, observability). An understanding of the fundamental concepts of random variables is necessary, but EE562a, "*Random Processes in Engineering*" is not a prerequisites. The fundamental concepts of random processes necessary for this course will be reviewed. By the same token, we will try to eradicate the Ito versus Stratonovich calculus confusion, which has plagued the development of stochastic control. Thus, except for this foundational material, we will try to make the course as self-contained as possible.

Instructor:

Dr. Edmond A. Jonckheere,
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Office hours:

TBA

Meeting time & place:

3:30-4:50 pm, TTh.; OHE100B

Grader:

TBA

Textbook:

- P. Dorato, C. Abdallah, and V. Cerone, *Linear-Quadratic Control—An Introduction*, Prentice Hall, 1995, ISBN: 0-02-329962-2. This is a very terse and concise monograph covering the most important aspects of linear-quadratic optimization and its traditional feedback interpretation. Those students finding it a bit too short are invited to look at the "supplemental texts."

Supplemental (recommended) texts:

- H. Kwakernaak and R. Sivan, *Linear Optimal Control Systems*, Wiley-Interscience, 1972, ISBN: 0-471-51110-2. This book is a little old, is missing latest developments, but it has remained a "classic" and should be easy to read for graduate students.
- B. D. O. Anderson and J. B. Moore, *Optimal Control—Linear-Quadratic Methods*, Prentice-Hall Information and System Science Series, 1990, ISBN: 0-13-638560-5. This book covers the state-space theory as well as its traditional feedback interpretations fairly well. It should not be too hard to read for graduate students. It contains some good aerospace examples of linear-quadratic optimization.
- V. Ionescu, C. Oara, and M. Weiss, *Generalized Riccati Theory and Robust Control*, Wiley, 1999, ISBN: 0-471-97147-2. This is probably the best book of its kind, but it is definitely beyond the scope of EE588. But it could be of interest to

students planning to pursue a Ph.D. thesis on linear-quadratic optimization and related techniques.

Homework:

One homework per week, assigned on Th., due the following Th.

Exams:

- One midterm (TBA)
- One final (TBA)

Weight:

Homeworks	15%
Midterm	35%
Final	50%
Total	100%

Course Summary:

<table>
<tr><th>Topics</th><th>Chapters in Dorato et al</th><th>Time table</th></tr>
<tr><td>Fundamental state-space Linear-Quadratic Regulator (LQR) problem</td><td>1,2</td><td>January 2010</td></tr>
<tr><td>Traditional feedback properties of LQR solution</td><td>3,4</td><td>February 2010</td></tr>
<tr><td>Review of stochastic processes, Kalman-Bucy filtering, and Linear Quadratic Gaussian (LQG) design</td><td>5,6</td><td>March 2010</td></tr>
<tr><td>Robustness aspects of LQG design: Loop Transfer Recovery (LTR) design</td><td>7</td><td>April 2010</td></tr>
<tr><td rowspan="3">Special topics: Students' choice between
1. Digital LQ(G) control with applications to Active Queue Management or video streaming
2. bounded real lemma introduction to H^{∞}design
3. Quantum control: Kushner-Stratonovich integral or Continuous measurement equation</td><td>8</td><td rowspan="3">May 2010</td></tr>
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*I. R. Petersen, B. D.O. Anderson and E.A. Jonckheere, ``A first principles solution to the nonsingular H^∞ control problem," *International Journal on Robust and Nonlinear Control*, vol. 1, pp. 171-185, 1991.

**Notes provided by Instructor.