Course Syllabus
ECE 7930 - Special Topics in Electrical Engineering
"Computational Optimal Control"
Summer 2003, Independent Study Course.

Instructor: YangQuan Chen, Center for Self-Organizing and Intelligent Systems (CSOIS)
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Office Hours: Friday 1:00 PM to 2:30 PM or by appointment.

Text:

- E. Polak. *Computational Methods in Optimization* (Mathematics in Science and Engineering Ser.: Vol 77). Academic Press; (October 1997)

Project Software

- Adam L. Schwartz, E. Polak and YangQuan Chen. RIOTS_95 a Matlab Toolbox for Solving General Optimal Control Problems. Demos and manual is available from http://www.schwartz-home.com/~adam or http://www.csois.usu.edu/ilc/riots/
- YangQuan Chen and Adam L. Schwartz. **RIOTS_95--a MATLAB Toolbox for Solving General Optimal Control Problems And Its Applications to Chemical Processes.** Chapter in Recent Developments in Optimization and Optimal Control in Chemical Engineering. Rein Luus Editor, Transworld Research Publishers. 2002 http://www.csois.usu.edu/publications/pdf/pub077.pdf

Reference Texts:

- Arthur E. Bryson. **Dynamic Optimization.** Addison-Wesley Publishing; 1st edition (June 1999) (434 pages)
- Elijah Polak. **Optimization: Algorithms and Consistent Approximation**s (Applied Mathematical Sciences (Springer-Verlag), Vol 124). Springer Verlag; (June 1997). (779 pages)
- John T. Betts. **Practical Methods for Optimal Control Using Nonlinear Programming**. Advances in Design and Control 3, ISBN 0-89871-488-5. 2001. (190 pages)

Prerequisites:
- ECE/MAE 6320 "Linear Multivariable Control" and
- ECE/MAE 6330 "Nonlinear and Adaptive Control".
- A good working knowledge of C and C++ programming and Matlab API using mix language programming.

- ECE/MAE 7360 “Robust and Optimal Control” is an added advantage but not compulsory.

Credits: 3

Course Load: 10 hours per week. 12 weeks.

Course Requirements:

2 Projects Using RIOTS_95	40 points
Further algorithm development based on RIOTS_95	40 points
1 Literature Survey Reports:	20 points

(The details will be sent via email.)

There is no Mid-term Exam and Final Exam.

Notes:
1. This course is designed for 12 weeks summer independent study.
2. To get 3 credits, you have to spend at least 10 hours a week and 120 hours in total in this course, although you have the *flexibility* to arrange your efforts.
3. A weekly discussion is encouraged (but not compulsory) in the Instructor’s office in the course office hour. Friday 1:00-2:30pm.
4. More emphasis will be put on the algorithm development based on current RIOTS_95 framework.
5. *Essential course materials will be given by the Instructor via emails.*

Course Description:

The goal of “Computational Optimal Control” is to lead the students, who want to numerically solve a broad class of dynamic optimization problems or optimal control problems (OCP), to the cutting edge “consistent approximation”-based techniques and the related software package RIOTS_95 originally developed by Dr Adam L. Schwartz.

Emphasis is put on the problem formulation and transcription so that with minimum efforts, the OCP can be solved by RIOTS_95 efficiently. Moreover, as a 7000-level course, research favor will be put in the possible new algorithm development, or the enhancement of RIOTS_95 to a new level in some aspects.

A Description of RIOTS_95 http://www.csois.usu.edu/ilc/riots

RIOTS is a group of programs and utilities, written mostly in C and designed as a toolbox for Matlab, that provides an interactive environment for solving a very broad class of finite-horizon optimal multi-variable control problems. This class includes problems with:

* Lagrange, Bolza and Mayer type objective functions
* Linear or Nonlinear dynamics
* Min-Max objective functions
* Free final time problems
* Variable initial conditions
* Endpoint equality and inequality constraints
* Trajectory inequality constraints on the states and controls
* Simple bounds on the controls and free initial conditions

The user can supply objective, constraint and dynamics functions as either object code or M-files. Derivatives of these functions should also be supplied.

The optimal control is an accumulation point of the solutions RIOTS obtains to a sequence of discretized optimal control problems. The Discretized problems are, in a specific sense, consistent approximations to the original continuous-time, optimal control problem. The discretized optimal control problems are constructed by integrating the system dynamics with one of four fixed step-size Runge-Kutta integration methods, a discretized solver or a variable step-size integration algorithm and by representing the controls as finite-dimensional B-splines. The integrations proceed over a (possibly non-uniform) mesh that specifies the spline breakpoints. Solutions of the discretized, finite-dimensional problems are obtained using one of three descent methods using standard nonlinear programming techniques. The solution obtained for one discretized problem can be used to automatically select a new integration mesh upon which the optimal control problem can be re-discretized to produce a new discretized problem. The new discretized problem will more accurately approximate the original, continuous-time optimal control problem. Hence, its solution will be more accurate. In practice, only a few such re-discretizations need to be performed to achieve an acceptable solution.

RIOTS provides three different programs that perform the discretization and solve the finite-dimensional discretized problem. The appropriate choice of optimization program depends on the type of problem being solved as well as the number of points in the integration mesh. In addition to these optimization programs, RIOTS also includes other utility programs that are used to refine the discretization mesh, to compute estimates of integration errors, to compute estimates for the error between the numerically obtained solution and the optimal control and to deal with oscillations that arise in the numerical solution of singular optimal control problems.

A complete description of RIOTS is contained in the RIOTS user's manual (91 pages). A postscript version of the user's manual is downloadable from the World Wide Web.