University Of California, Berkeley
Department of Mechanical Engineering

ME 290J – Predictive Control for Linear and Hybrid Systems - 3 units

Graduate Course

Syllabus

CATALOG DESCRIPTION

Advanced optimization, polyhedra manipulation, and multiparametric programming. Invariant set theory. Analysis and design of constrained predictive controllers for linear and nonlinear systems. Computational oriented models of hybrid systems. Analysis and design of constrained predictive controllers for hybrid systems.

COURSE PREREQUISITES

ME C232 and ME C231A

TEXTBOOK(S) AND/OR OTHER REQUIRED MATERIAL

Online Free and Open Source Resources

COURSE OBJECTIVES

The course is designed for graduate students who want to expand their knowledge on optimization-based control design. 50% will be focusing on advanced theory. 50% on applications.

DESIRED COURSE OUTCOMES

At the end of the course, the students will write a theoretical paper on MPC and will design an experiment where the theory is implemented.

TOPICS COVERED

Advanced optimization, polyhedra manipulation, and multiparametric programming. Invariant set theory. Analysis and design of constrained predictive controllers for linear and nonlinear systems. Computational oriented models of hybrid systems. Analysis and design of constrained predictive controllers for hybrid systems.

CLASS/LABORATORY SCHEDULE

Two lectures per week

CONTRIBUTION OF THE COURSE TO MEETING THE PROFESSIONAL COMPONENT

Optimization-based control design is highly requested skill from a number of industries, including automotive, aerospace, process control and manufacturing. The course will provide the students with a solid theoretical background needed for hi-tech industries, as well as with tools for implementing optimization-based control design.

ASSESSMENT OF STUDENT PROGRESS TOWARD COURSE OBJECTIVES

10% Homework
20% Midterm 1
20% Midterm 2
50% Final.

TOPICS COVERED/WEEKLY AGENDA

Optimization

- Basis Concept of Optimizations
  - Min/Inf, Feasible, Active Constraint, Redundant Constraint, Global and Local Optimum
  - Linear Program, Quadratic Program, nonlinear program
  - Convexity: definition, importance, convex optimization problems
- Optimality conditions
  - Necessary and sufficient optimality conditions for unconstrained optimization problems
  - Duality theory: Main concepts, what is used for, how to write a dual of an optimization problem
  - Strong duality: Definition and concept of constraints qualifications
  - KKT conditions
- Polyhedra
  - H- and V- representation
  - Function defined on Polyhedra
  - Basic Operations on Polytopes
  - Minkowsky sum, Pontriagin difference and their application to composition with linear function.
- LPs and QPs
  - Definitions, solution properties
  - Number of active constraints and multiple optima (LP)
  - Dual of LPs and QPs
  - Convex Piecewise-linear Optimization
- Multiparametric Programming
  - Main idea.
  - Main Concept of Critical Region.
  - Solutions properties of mpLP and of mpQP

Optimal Control

- General Formulation of constrained control problems
  - Finite time, Infinite time
  - Value function, Feasible sets
- Solution Finite time
  - Batch Approach (with and without substituting the dynamics)
  - Principle of Optimality and Dynamic Programming (DP)
  - Comparison Batch vs DP
- Solution of Infinite Time
  - Value Function iteration

- Solution with Receding Horizon
- Review of Unconstrained case
    - Finite time LQR (via batch and via DP)
    - Infinite time LQR
    - Lyapunov Stability
    - Solution via DP and gridding

- Constrained 2-Norm Optimal Control
    - Solution via Batch Approach and online optimization.
    - Use of Multiparametric Programming : Solution via Batch
    - Properties of the state-feedback solution
    - Infinite horizon properties

- Constrained 1/∞ Norm Optimal Control (less important than 2 norm)
    - Solution via Batch Approach and online optimization
    - Solution via DP and gridding
    - Use of Multiparametric Programming : Solution via Batch and DP
    - Properties of the state-feedback solution
    - Infinite horizon properties -> not covered….

- Controllability, reachability and invariance
    - 11.1 Controllable and Reachable Sets
    - 11.1.1 Computation of Controllable and Reachable Sets
    - 11.2 Invariant Sets

Receding Horizon Control

- Definition, Notation and Basic Algorithm.
- Feasibility issue: Problems and Solutions. Persistent feasibility and Persistent feasibility for all feasible inputs. Methods for guaranteeing persistent feasibility.
- Main Theorem of RHC (Stability and Feasibility): proof
- Tuning and Practical Rules
- Zero steady-state tracking RHC
- Online and Offline RHC implementations

Robust Optimal Control

- Main definition
- Uncertain linear systems with additive and parametric uncertainty
- Choice of Cost, Constraints and Open loop vs Closed Loop predictions (18 designs)
- Difference between Batch approach (also called with open-loop predictions) and Recursive approach (also called with closed-loop predictions)
- Robustification of constraints (1-step, N-steps and iInfinite Steps (Invariants))
- Robust MPC stability and feasibility theorem

Hybrid Systems

- Main idea
- PWA systems
- DHA systems

- MLD systems
- Basic results on optimal control for hybrid systems (MILP/MIQP or explicit solution)

PERSON(S) WHO PREPARED THIS DESCRIPTION

Francesco Borrelli, 10/1/2015

ABBREVIATED TRANSCRIPT TITLE (19 SPACES MAXIMUM): ADV CONTRL SYS I
TIE CODE: LECS
GRADING: Letter
SEMESTER OFFERED: Fall and Spring
COURSES THAT WILL RESTRICT CREDIT: None
INSTRUCTORS: Staff
DURATION OF COURSE: 14 Weeks
EST. TOTAL NUMBER OF REQUIRED HRS OF STUDENT WORK PER WEEK: 9
IS COURSE REPEATABLE FOR CREDIT? No
CROSSLIST: None