ONE-DAY TUTORIAL WORKSHOP

American Control Conference, 2007

Uncertain System Control: An Engineering Approach

Stefen Hui, San Diego State University
Stanislaw H. Żak, Purdue University

Control engineers face a widening gap between "real world" control problems and the theory for the analysis and design of linear control systems. Design techniques based on the linear system theory cannot accommodate nonlinear effects and modeling uncertainties. Effective control strategies are required to achieve high performance for uncertain dynamical systems. In addition, most engineering problems require solutions that satisfy multiple objectives. Often, these objectives are in conflict with each other, that is, an improvement in one objective leads to deterioration in another. Multi-objective problems in which there is competition between objectives usually have multiple optimal solutions.

The aim of this workshop is to present a tutorial on the theory and design of controllers for uncertain system that is suited for an engineering audience rather than a research oriented audience. The emphasis will be on design in order to show how uncertain system control theory fits into practical applications.

Participants will first be introduced to the basic components of controllers for uncertain system that include adaptation, learning, fuzzy logic, neural networks, and genetic algorithms. An overview of the Lyapunov stability theory, followed by an introduction to adaptive control using neural fuzzy networks will be presented. Then, participants will learn how to combine these ingredients to obtain sensory interactive control structures incorporating cognitive characteristics to emulate learning behavior with a capacity for performance or parameter adaptation. Multi-objective optimization will be introduced to show how it can provide the designer with good information about available trade-offs.

The intended audience includes practitioners who are primarily interested in applying modern control techniques, engineers who desire an introduction to the concepts and tools that can be used to design high performance controllers capable of accommodating modeling uncertainties and system complexities, and faculty members, as well as graduate students, who wish to acquaint themselves with some of the more advanced techniques.

SCHEDULE

- 8:30--9:15 Proportional-Integral-Derivative (PID) Control Framework---A Method to Control Uncertain Systems
    - The Ziegler-Nichols PID tuning methods
    - Remedies for derivative action
    - The set-point kick phenomenon
    - Three types of PID controllers
    - Computational approach to optimize the PID controller parameters
    - Numerical example---Generating an optimal set of PID parameters for the DC motor PID controller's parameters

- 9:15--10:15 Fuzzy Logic Control---Another Tool in Our Control Toolbox to Cope With Uncertainties
    - Linguistic modeling of dynamical systems---fuzzy logic
    - Notion of a fuzzy set
    - Fuzzy numbers, linguistic variables, fuzzy rules
    - Defuzzification: Moving from fuzzy rules to numbers
    - Fuzzy Logic Control (FLC) design algorithm
    - Example: Designing a fuzzy logic controller for the DC motor

- Break

- 10:30--11:15 Analysis Tools of Nonlinear or Uncertain Systems
    - Objectives of analysis of nonlinear systems
    - Summarizing function
    - Equilibrium points for linear and nonlinear systems
    - Definition of stability in the sense of Lyapunov
    - Asymptotic stability---Convergence alone does not guarantee asymptotic stability in the sense of Lyapunov (Hahn's 1967 example)
    - Lyapunov's first method
    - Lyapunov functions
    - Lyapunov Theorem

- 11:15--12:00 Estimating Region of Asymptotic Stability
    - Quadratic forms and tests for checking their sign definiteness
    - Lyapunov matrix equation
    - How not to use the Lyapunov theorem
    - Limitations of the Lyapunov method
    - Some properties of time-varying functions
    - Continuity and uniform continuity
    - Barbalat's lemma
    - Lyapunov-like lemma
    - Examples

- Lunch Break

- 1:00--1:45 Variable Structure Sliding Mode Control
    - Basic vocabulary: variable structure system, switching surface, sliding mode behavior
    - Some useful properties of variable structure systems
    - The reachability condition
    - Discontinuous control law
    - Sliding mode controller design---A two phase process
    - Switching Surface and Sliding Mode Controller Design
    - Order reduction of the system dynamics in sliding
    - Equivalent control
    - Sliding mode control of uncertain systems
    - Robustness of sliding mode controller
    - Example---sliding mode controller design for the DC motor

- 1:45--2:30 Fuzzy Adaptive Robust Control (FARC) of Uncertain Systems
    - Uncertain plant model
    - Fuzzy Adaptive Robust Control (FARC) Architecture
    - Fuzzy logic component
    - Adaptation law
    - Robustifying component
    - Synergetic control ---notion of a macro-variable
    - Relations of synergetic control with sliding mode control
    - Example---FARC design for the DC motor
    - Comparing the FARC and PID controller performance

- 2:30--3:00 Variable Structure Self-Organizing Neural Fuzzy Controller
    - Radial basis function (RBF) neural net
    - Raised-cosine RBF neural net
    - Combining center-average defuzzifier with neural net
    - Self-organizing algorithm
    - Controller design algorithm
    - Equipping neural radial basis function (RBF) fuzzy controller with self-organizing characteristics

- Break

- 3:15--4:00 Genetic Algorithms
    - Genetic algorithm (GA)---a new design toll for modern control engineer
    - Flowchart of a genetic algorithm
    - Genetic opearators
    - Implementation issues
    - Using genetic algorithms to optimize controller's parameters

- 4:00--4:45 Multi-Objective Optimization
    - Optimal solution in multi-objective optimization
    - Non-dominated solution and Pareto solution
    - Pareto front
    - Comparing a new feasible solution with the existing Pareto solutions
    - Numerical example---selecting optimal PID controller parameters using multi-objective optimization approach

- 4:45--5:30 Multi-Objective Search With Genetic Algorithms
    - The task of a multi-objective optimizer---provide the designer with good information about available trade-offs.
    - Using the Multi-Objective Genetic Algorithm (MOGA) to tune the parameters of a three-term controller