Model Predictive Control Workshop

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Rationale

Model predictive control (MPC) has become the most popular advanced control method in use today. Its main attractive features are (i) optimization of a model forecast over the available actuators (ii) estimation of the state of the system and disturbances from the process measurements, (iii) accounting for the process and actuator constraints, and (iv) accounting for full multivariable interactions. After its introduction in the process industries in the 1970s, MPC has today become a pervasive control technology in many industries, and is now being increasingly deployed for optimization of high-level functions such as minimizing energy consumption and maximizing product quality.

This short course is intended to introduce graduate students and practitioners to the theory and design of MPC systems.

The two days of lectures will cover the following topics.

1. Introduction, dynamic modeling, predictive control versus classical PID control.

2. Model predictive control: regulation problem, linear quadratic regulator, constraints, dynamic programming, infinite horizon, LQR, constrained regulation.

3. State estimation: least-squares estimator, Kalman filter, observability and convergence.

4. Putting regulation and estimation together, industrial practice, disturbance models, and offset.

5. Nonlinear MPC. introduction, stability, Lyapunov function theory, disturbances and robust stability, nominal stability, suboptimal MPC, inherent robustness of optimal and suboptimal MPC, some examples.

6. Other topics: distributed MPC, economic MPC, and hybrid MPC.

Tentative schedule. The tentative schedule for the two-day workshop is attached.

About the presenters

James B. Rawlings. He received the B.S. from the University of Texas in and the Ph.D. from the University of Wisconsin, both in Chemical Engineering. He spent one year at the University of Stuttgart as a NATO postdoctoral fellow and then joined the faculty at the University of Texas. He moved to the University of Wisconsin in 1995 and is currently the Paul A. Elfers Professor and W. Harmon Ray Professor of Chemical and Biological Engineering, and the co-director of the Texas-Wisconsin-California Control Consortium (TWCCC).

Professor Rawlings's research interests are in the areas of chemical process modeling, monitoring and control, nonlinear model predictive control, moving horizon state estimation, and molecular-scale chemical reaction engineering. He has written numerous research articles and coauthored three textbooks: "Modeling and Analysis Principles for Chemical and Biological Engineers" (2013) with Mike Graham, "Model Predictive Control: Theory and Design" (2009), with David Mayne, and "Chemical Reactor Analysis and Design Fundamentals," 2nd ed. (2012), with John Ekerdt.

In recognition of his research and teaching, Professor Rawlings has received several awards including:

- "Doctor technices honoris causa" from the Danish Technical University;
- Inaugural High Impact Paper Award from the International Federation of Automatic Control;
- Ragazzini Education Award from the American Automatic Control Council;
- Computing in Chemical Engineering Award and Excellence in Process Development Award from the AICHE;
- Chancellor's Distinguished Teaching Award, WARF Named Professorship, and the Byron Bird Award for Excellence in a Research Publication, from the University of Wisconsin;

He is a fellow of IEEE and AIChE.

Thomas A. (Tom) Badgwell. He is a Research Associate in the Data Analytics & Optimization Section, Corporate Strategic Research, at the ExxonMobil Research & Engineering Company in Clinton, NJ. He received a B.S. degree in Chemical Engineering from Rice University and M.S. and Ph.D. degrees from the University of Texas at Austin. Tom's career has focused on research, development, and application of MPC technology, with past positions at Setpoint, Fisher/Rosemount, Rice University, and Aspen Technology. He received the

2005 Control Engineering Practice Best Paper Prize for his MPC survey article with Professor Joe Qin (2003). He received the 2013 AIChE Computing and Systems Technology Division Computing Practice Award for his contributions in the theory and practice of MPC applied to the process industries. He is a fellow of AIChE, an Associate Editor for the Journal of Process Control, and serves as a Trustee of the Computer Aids in Chemical Engineering (CACHE) Corporation.

References

S. J. Qin and T. A. Badgwell. A survey of industrial model predictive control technology. *Control Eng. Pract.*, 11(7):733–764, 2003.

J. B. Rawlings and D. Q. Mayne. *Model Predictive Control: Theory and Design.* Nob Hill Publishing, Madison, WI, 2009. 576 pages, ISBN 978-0-9759377-0-9.

Schedule: Model Predictive Control Workshop

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June 29–30, 2015

American Control Conference, Chicago, IL

Session 1: Monday 8AM to 11:30AM

1. Introduction to MPC
   (a) Overview and Industrial Impact
   (b) Dynamic Modeling
      - CT Linear Differential Equations
      - CT Transfer Functions
      - DT Linear Difference Equations
      - Software
   (c) Predictive Control versus Classical PID Control
      - Difficult Dynamics
      - Constraints
      - Multivariable Interactions
   (d) Summary
2. Regulation (Part 1)
   (a) Linear Quadratic Regulator
   (b) Constraints
      - Physical
      - Rate-of-Change

Lunch: Monday 11:30AM to 12:30PM

Session 2: Monday 12:30PM to 4PM

2. Regulation (Part 2)
   (c) Dynamic Programming Solution
      - $N = 1$ Case
      - Riccati Iteration
      - Potential Pitfalls
      - Stability
   (d) Infinite Horizon LQR
      - Controllability
      - Convergence of the LQR
   (e) Constrained Regulation
      - Quadratic Programming
      - Terminal Constraints
3. State Estimation
   (a) Deterministic and Stochastic Systems
      - Least-Squares Estimation
      - Kalman Filter
   (b) Observability
      - Test for Observability
   (c) Convergence of the Estimator
      - Regulation/Estimation Duality

Session 3: Tuesday 8AM to 11:30AM

4. Putting It All Together
   (a) Setpoint Tracking
      - Deviation Variables
      - Steady-state Target Problem
      - Dynamic Regulation Problem

   (b) State Estimation, Disturbance Models, and Zero Offset

5. Nonlinear MPC (Part 1)
   (a) Introduction
   (b) Stability, equilibria, invariant sets
   (c) Lyapunov function theory
   (d) Disturbances and robust stability
   (e) Basic MPC regulation problem and nominal stability

Lunch: Tuesday 11:30AM to 12:30PM

Session 4: Tuesday 12:30PM to 4PM

5. Nonlinear MPC (part 2)
   (a) Suboptimal MPC
   (b) Inherent robustness of optimal and suboptimal MPC
   (c) Analysis of a troublesome example
   (d) Conclusion

6. Other Topics
   - Distributed MPC
   - Economic MPC
   - Hybrid MPC