ALGORITHMIC APPROACHES TO INTEGRATED DESIGN AND CONTROL

Motivation

- Classical design approach
  - Steady State Model
  - Simulation
  - Optimal design at Nominal Conditions
  - Arbitrary
  - Control under Fixed Design Phase

- Problem Decomposition
  - Problem Decomposition Algorithm (Mohdow et al. 1996)
    - Design optimization problem is separated from feasibility test.
    - Main optimization problem is solved in discretized sampling space.
    - Feasibility test is followed by optimization problem.

- Simultaneous Design and Control optimization
  - Maximizes overall system performance in face of operational and model uncertainty.
  - Quantifies the actual dynamic process and prevent dynamic constraint violation.
  - Integration renders non-polynomial (NP) hard non-convex MINLP.
  - Nondimensionalization methodology.

- Simultaneous Design and Control Optimization
  - Maximize overall system performance in face of operational and model uncertainty.
  - Quantifies the actual dynamic process and prevent dynamic constraint violation.

Simultaneous Design and Control

- Problem Decomposition
  - Problem Decomposition Algorithm (Mohdow et al. 1996)
    - Design optimization problem is separated from feasibility test.
    - Main optimization problem is solved in discretized sampling space.
    - Feasibility test is followed by optimization problem.

- Simultaneous Design and Control Optimization
  - Stochastic optimization problem defined over the finite sample set.
  - Optimize design and control parameters for minimum expected operating cost and capital cost.

- Rigorous Flexibility Test
  - Ensure constraints satisfaction for all uncertain realizations.
  - Find critical scenarios.

Embedded Control Optimization

- Embedded Control Optimization
  - Mapping dynamic process model into a linear state space model.
  - Ensured in every time step of discretized time.
  - Identification methods
    - Sequential least squares method.
  - Estimation
    - Minimizes the prediction error
    - Measurement noise
    - Process noise
    - Observation noise.
  - Regulation: Optimal control action
    - Linear Quadratic Regulator (LQR)
    - Model Predictive Control (MPC)

Rigorous Flexibility Test

- Ensure constraints satisfaction for all uncertain parameter space.
- Find critical uncertain values.
- Steady state feasibility test is done first, then dynamic feasibility test is done.
- Stochastic optimization problem defined over the finite sample set.
- Optimize design and control parameters for minimum expected operating cost and capital cost.

- Embedded Control Optimization
  - Ensures feasibility for all uncertain parameter space.
  - Finds critical uncertain values simultaneously.
  - Minimizes the prediction error.
  - Measurement noise.
  - Process noise.
  - Observation noise.

Case Study - Integrated Design and Control of Ternary Distillation Column

- Ternary distillation Column
  - Dynamic model of distillation column.
  - Accounts for hold-ups.
  - Multi-Input, Multi-Output control.
  - Non-linear system.

- Components
  - Pentane (z1), Hexane (z2), Heptane (z3).

- Variables Categories
  - State: Liquid, vapor, reboiler, reboiler.
  - Control: Steady state, vapor ratio, vapor, reboiler.

- Inlet Scenarios
  - Input feed changes: 0.35x1–0.35x2–0.35x3.

- Control activity (0-4550)
  - Control activity (0-4550).

- Costs Calculation
  - Operating costs.
  - Capital costs.
  - Total costs.

- Master optimization problem was solved by Genetic algorithms.

Conclusions

- Future work
  - Different algorithms should be considered and tested.
  - More challenging case studies must be done.

Acknowledgements

- Andreas Malcolm, Research Engineer, Cargill, Minneapolis, MN.
- NSF Grant CBET-0826102.

References