Integrated System Identification and PID Controller Tuning by Frequency Loop-Shaping

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Outline

- Problem Description: PID Tuning from Input-Output data
- System Identification and Estimation of Uncertainty Bounds
  - Additive/Multiplicative Uncertainty
  - Coprime Factor Uncertainty
- Target Loop Selection and PID Tuning
  - 1st, 2nd order targets
  - Convex optimization to solve a special model matching problem
  - Tuning for multiple models
- Experimental Results
  - Reactor Bed Temperature Control
  - Fractionator Inlet Header Pressure Control
- Conclusions

Problem Description

- Industrial Applications
  - Reliability and Expediency Requirements
- Modeling from I/O data
  - System Identification
- Uncertainty estimation
  - Target performance determination
- Controller design
  - Specifications in terms of a target loop or target sensitivities
  - “Minimize” sensitivity subject to bandwidth constraints

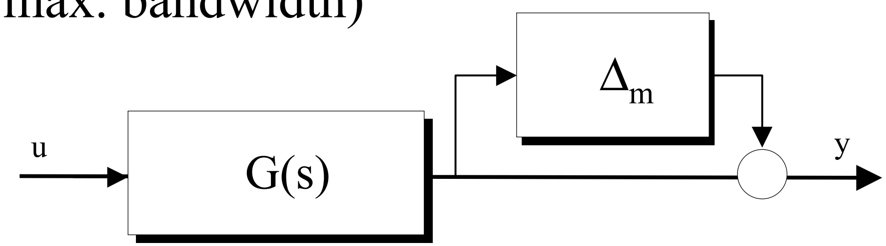
System Identification

- Identification experiment
  - Steps, PRBS, other
  - Choice of excitation: Good SNR in the frequency range of interest (intended crossover)
- Estimation of nominal model (various approaches)
- Uncertainty bound estimation (different uncertainty structures)
  - Additive/Multiplicative (T-bound, max. bandwidth)
  - Coprime Factors (S+T bounds, concurrent selection of the target loop, simpler targets for PIDs)
  - Guide: Robust Stability Condition

System Identification (cont.)

- Uncertainty structures
  - Multiplicative (T-bound, max. bandwidth)

$$|T(jw)||\Delta_m(jw)| < 1$$



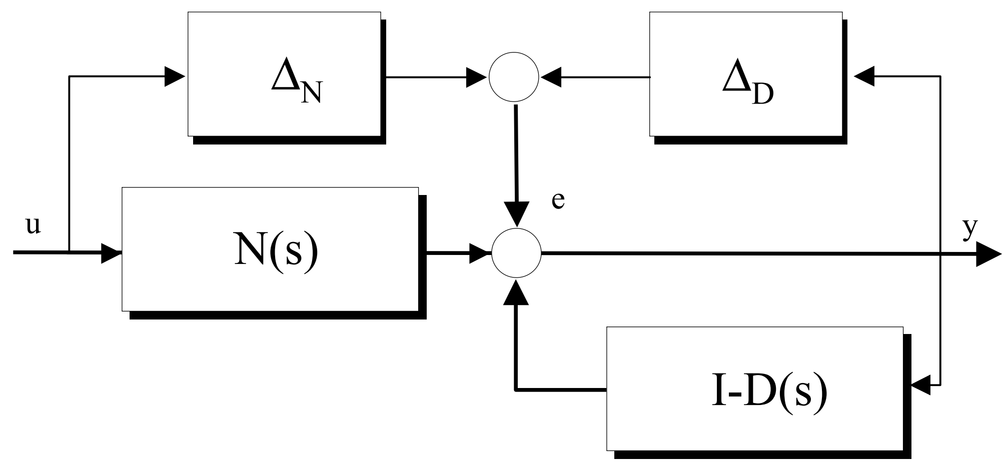
  - Coprime Factors (S+T bounds)

$$|G^{-1}TD^{-1}||\Delta_N| + |SD^{-1}||\Delta_D| < 1$$

$$\approx$$

$$|T||N^{-1}||\Delta_N| < 1 \quad (hi-freq)$$

$$|S||D^{-1}||\Delta_D| < 1 \quad (lo-freq)$$



Target Loop Selection and PID Tuning

- Typical Targets: $\frac{\lambda}{s}, \quad \frac{\lambda(s+a)}{s^2}, \quad \frac{\lambda(s+a)}{s(s+\varepsilon)}, \quad \dots$
  - Target order depends open-loop/closed-loop bandwidth ratio (for input disturbance attenuation)
  - Uncertainty constraints and RHP pole-zero limitations
  - More difficult cases via LQ or full-order controller design methods e.g., K=lqr(A,B,Q,R), target: [A,B,K]
- FLS Tuning: convex optimization in the frequency domain

$$\min_{K_{pid}} \left\| S(GC_{K_{pid}} - L) \right\|_{L_\infty} \qquad s.t. \quad K_{pid} \quad constr.$$

$$\min_{K_{pid}} \left\| S(GC_{K_{pid}} - L) \right\|_{L_2} \qquad s.t. \quad \left\| S(GC_{K_{pid}} - L) \right\|_{L_\infty} \le b, \quad K_{pid} \quad constr.$$

Target Loop Selection and PID Tuning (cont.)

- A Special Case of Interest: Multiple plants
- FLS Tuning with multiple target loops
  - Target loops can be fixed, or
  - Target loop bandwidth can be an argument of the optimization (first order targets)

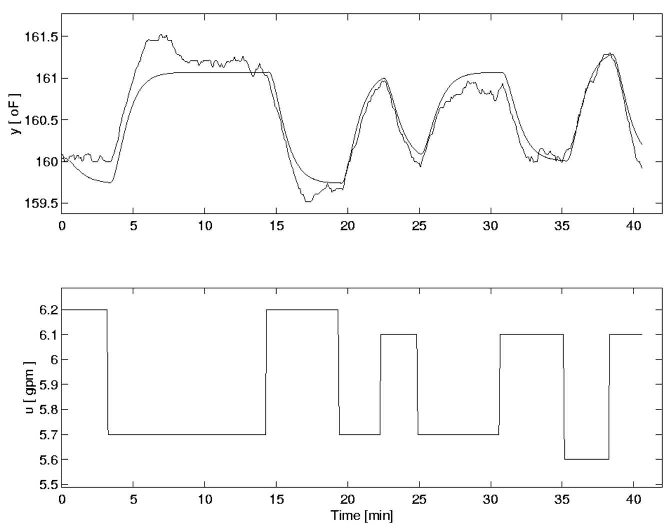
$$\min_{K_{pid}} \left\| \begin{matrix} S_1(G_1 C_{K_{pid}} - L_1) \\ \vdots \\ S_m(G_m C_{K_{pid}} - L_m) \end{matrix} \right\|_{L_\infty}$$

$$s.t. \quad K_{pid} \quad constr.$$

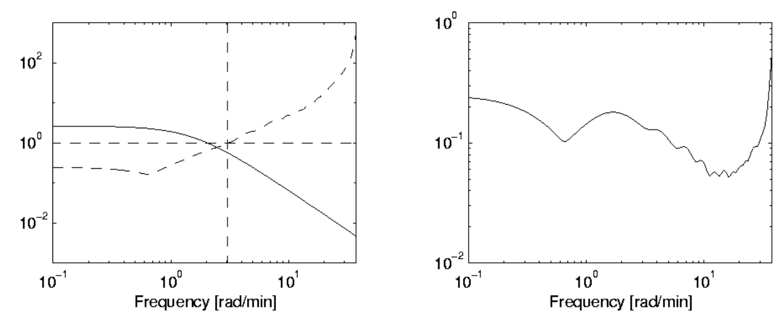
Experimental Results 1

- Several Successful Field Tests
- Reactor Bed Temperature Control
  - System Identification (2nd order model + delay)
  - 1st order target, PI control

Actual vs. Predicted response



Estimated mult. Uncertainty and RSC



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Experimental Results 1 (cont.)

- Closed Loop Response
  - (before and after)

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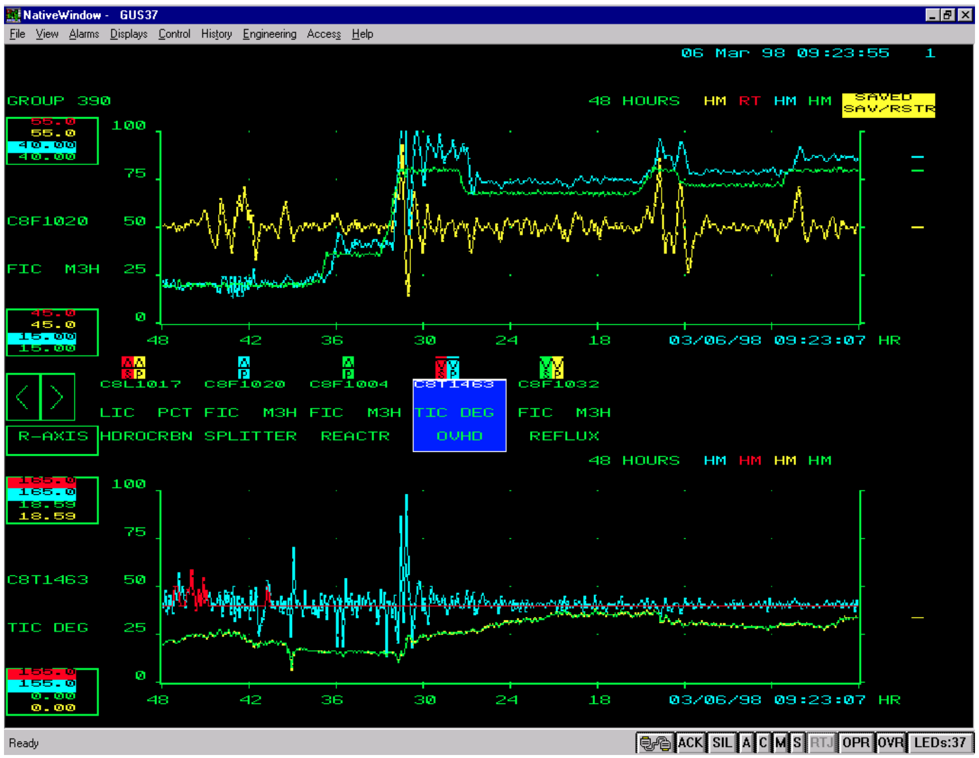
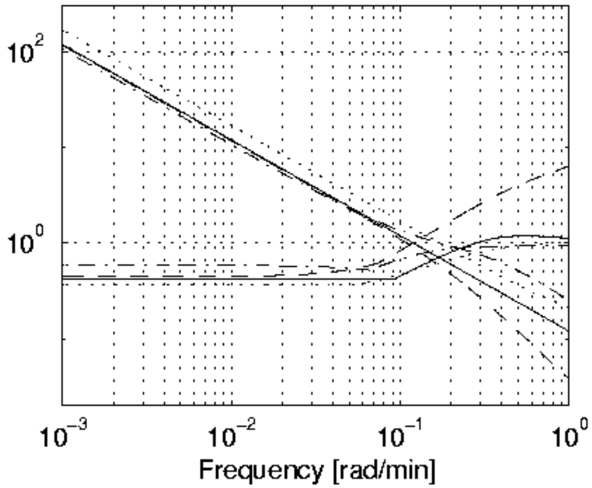


Levels and Flows

Reflux Flow rate and Inlet Temperature

Experimental Results 2

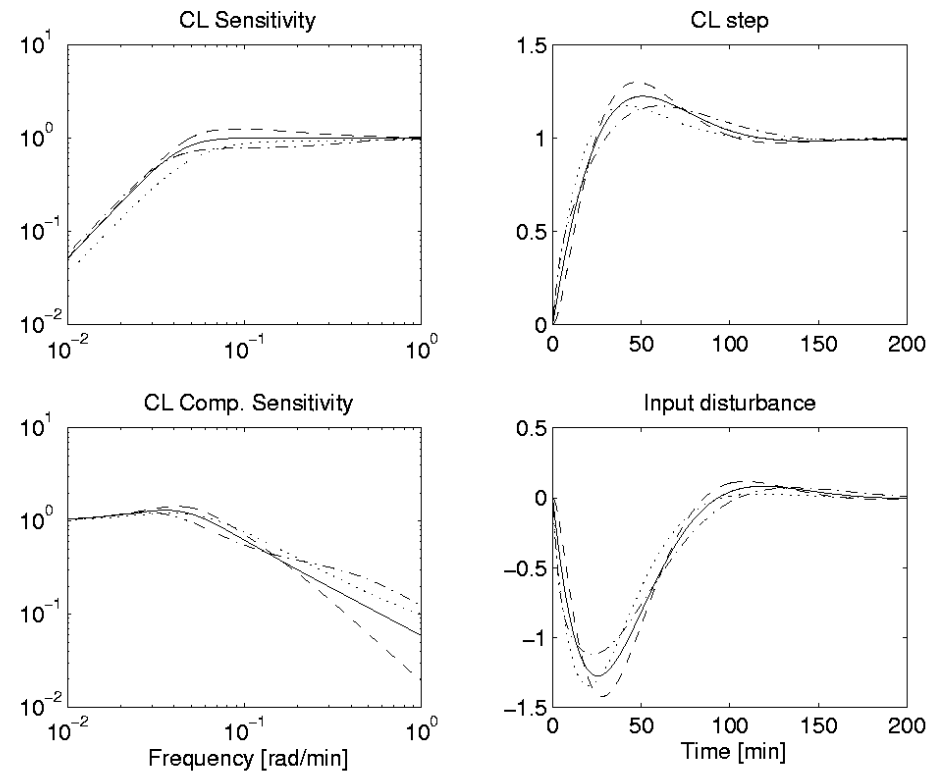
- Fractionator Inlet Header Pressure Control
  - 4 models (lack of data)
  - Integrating plants
  - Bandwidth constraints from the model differences
  - Target loop: 2nd order, 20% overshoot, PI controller



Plant model frequency responses and multiplicative uncertainty

Experimental Results 2 (cont.)

- Closed-Loop Responses
  - Simulated (no recorded data)
  - Consistent with observations
- Higher Bandwidth PI's resulted in lightly damped or oscillatory behavior



Conclusions

- Integrated identification and PID tuning
- Uncertainty estimation: important in determining feasible targets
- Quantitative measure of confidence
- Excellent disturbance attenuation properties are a result of sensitivity minimization
- Reliable controllers (minimal iterations, work well the first time)
- Software tools make the design “easy” (for most cases)
  - Highly automated, Numerically reliable, Modest expertise requirements
  - Quick solutions to typical problems; hard problems still stay hard!