Simple criteria for controller performance monitoring

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- Introduction/motivation
- Performance monitoring philosophy
- Simple criteria based on small-gain arguments
  - Excitation, disturbances, bounds
  - Misses vs. False Alarms
- Illustrative examples and Conclusions

Introduction

- Need for Performance Monitoring
  - Thousands of control loops
  - Long maintenance cycles
  - Severe economic impact
- Performance: variability, disturbance rejection
- Automatic monitoring issues:
  - Disturbances and modeling error
  - Normal operating data vs. injection of excitation

Monitoring Philosophy

- Minimum Variance Control
  - Regulation objectives, stochastic disturbances
  - Time-series analysis (Harris), H-2 objectives (Huang)
- Frequency-Domain techniques
  - System identification excitation
  - Sensitivity (Cinar), Gap metric (Huang)
- Optimal design criteria
  - Unfalsification (Safonov)
- Deviation from Nominal
  - Small-Gain Theorem => Robust stability conditions

Monitoring Issues

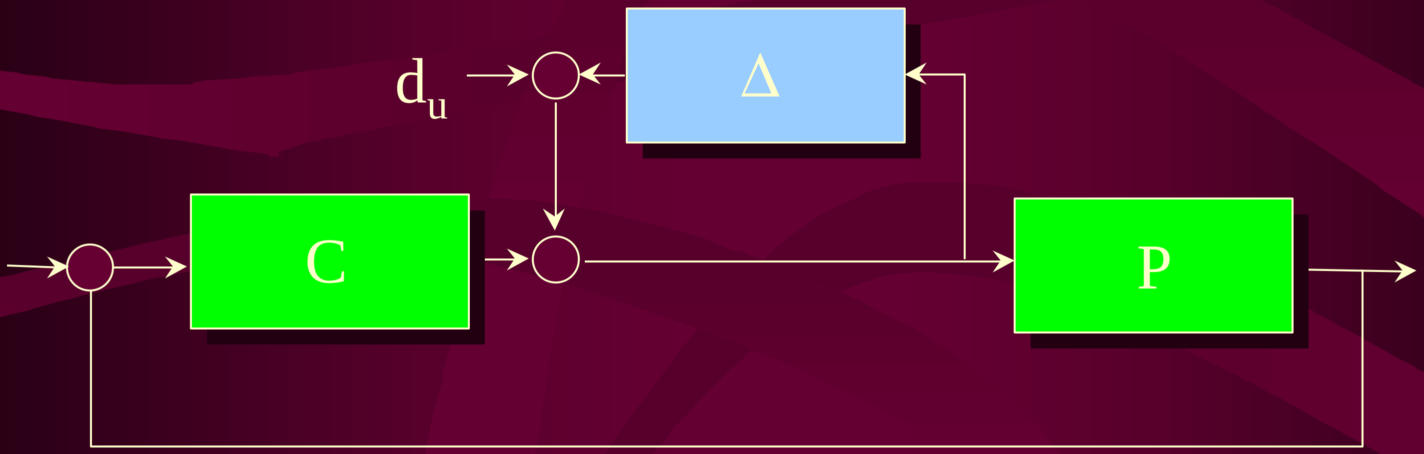
- Excitation
  - Normal operating data, set-point changes, injection of identification-level excitation
  - Conclusions based on partial information
- Disturbances
  - Bound on the “normal” level of disturbances
- Misses vs. False Alarms
  - Unfalsification: Avoid false alarms

Simple Monitoring Criteria

- Deviation from Nominal Behavior
- Plant-model mismatch (sensitivity-weighted)
- A variety of criteria depending on the assumed uncertainty structure
  - Controller-in-the-loop requirements
  - Conditions on actuator saturation
  - Effect of bounded disturbances
  - Resolution

Monitoring at the plant input

- Small gain condition at the plant input
- Feedback uncertainty, external disturbance



Reject controller if $$\frac{\| S_u C[y] - T_u[u] \| - \| d \|}{\| u \|} > 1$$

Monitoring at the plant input (cont.)

Reject controller if $$\frac{\| S_u C[y] - T_u[u] \| - \| d \|}{\| u \|} > 1$$

- A weighted plant modeling error

$$S_u C P_{actual} - T_u = S_u C(P_{actual} - P_{nominal})$$

- Computation independent of controller-in-the-loop
- Valid for saturating actuators and partial excitation
  - Without known excitation, LHS ~ 1 for a well-tuned controller, and >>1 for a poorly tuned controller
- “Normal” disturbance estimate is critical for the reduction of false alarms

Monitoring at the plant output

Reject controller if $$\frac{\| y - T_y[r] \| - \| d \|}{\| r - y \|} > 1$$

- Appealing performance metric
- Requires the controller-in-the-loop
- Restricted to non-saturating actuators
- “Normal” disturbance estimate is critical for the reduction of false alarms

Monitoring with coprime factor uncertainty

Reject controller if

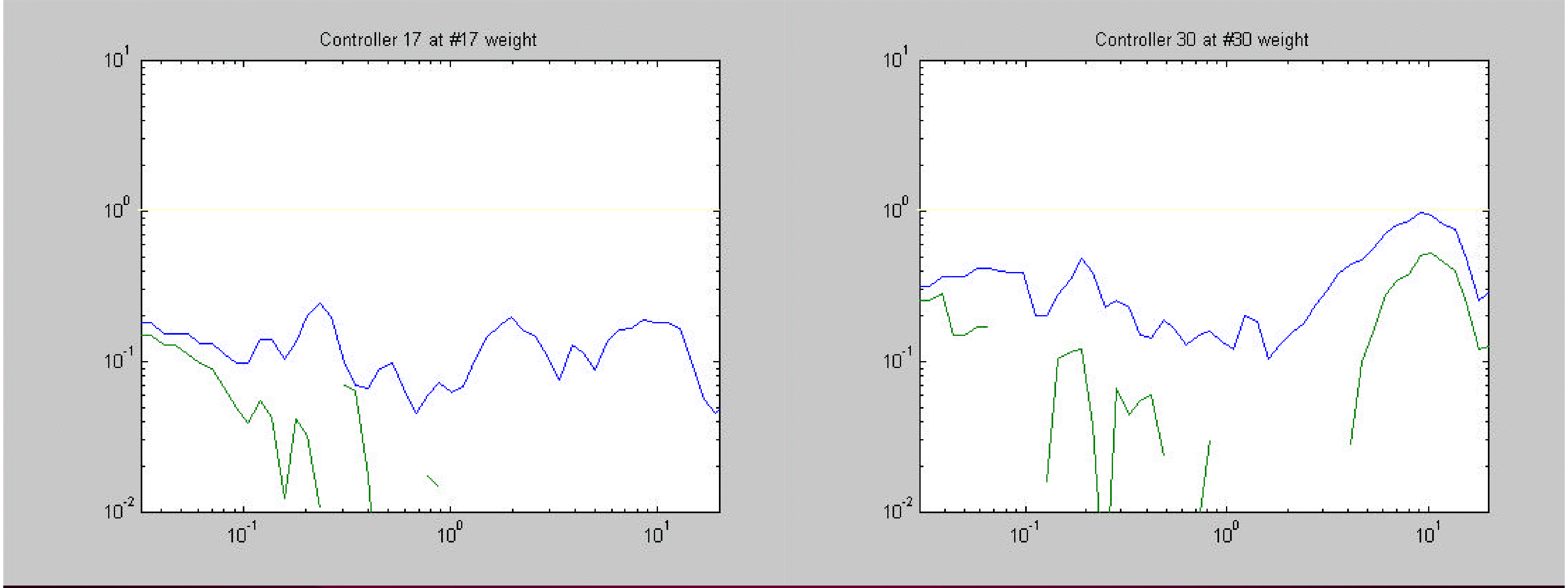
$$\boldsymbol{s}[CS_y D^{-1}]\boldsymbol{d}_N + \boldsymbol{s}[S_y D^{-1}]\boldsymbol{d}_D > 1$$

$$\boldsymbol{d}_N, \boldsymbol{d}_D = \ldots$$

- Independent of controller-in-the-loop
- Valid for saturating actuators
- “Normal” disturbance estimate is critical for the reduction of false alarms

Simulated example: Paper machine

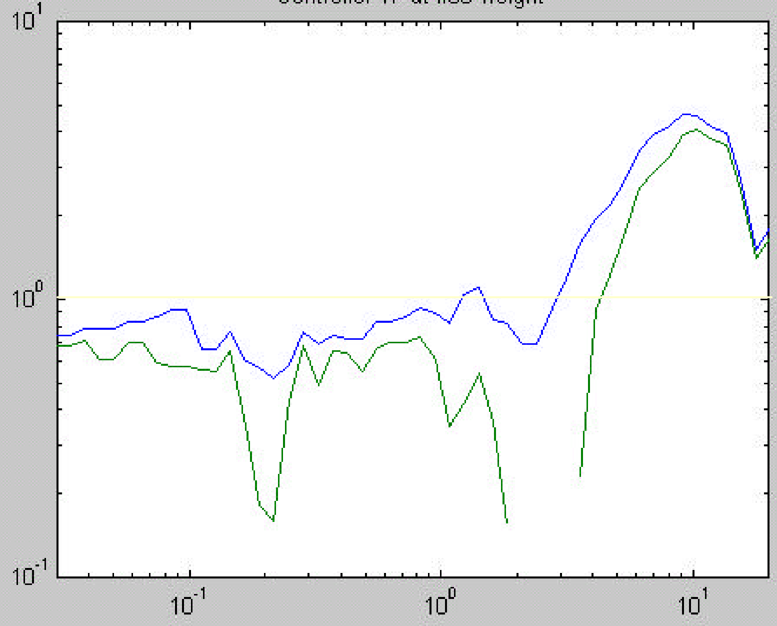
- Monitoring at the plant input
- Two grades of paper, external excitation



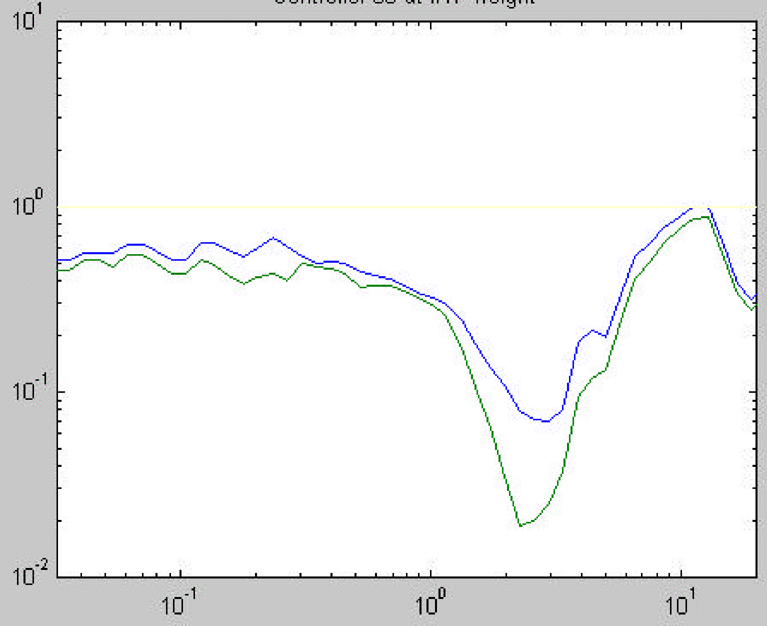
Simulated example: Paper machine (cont.)

- Poor performance far from the nominal operating point

Controller 17 at #30 weight

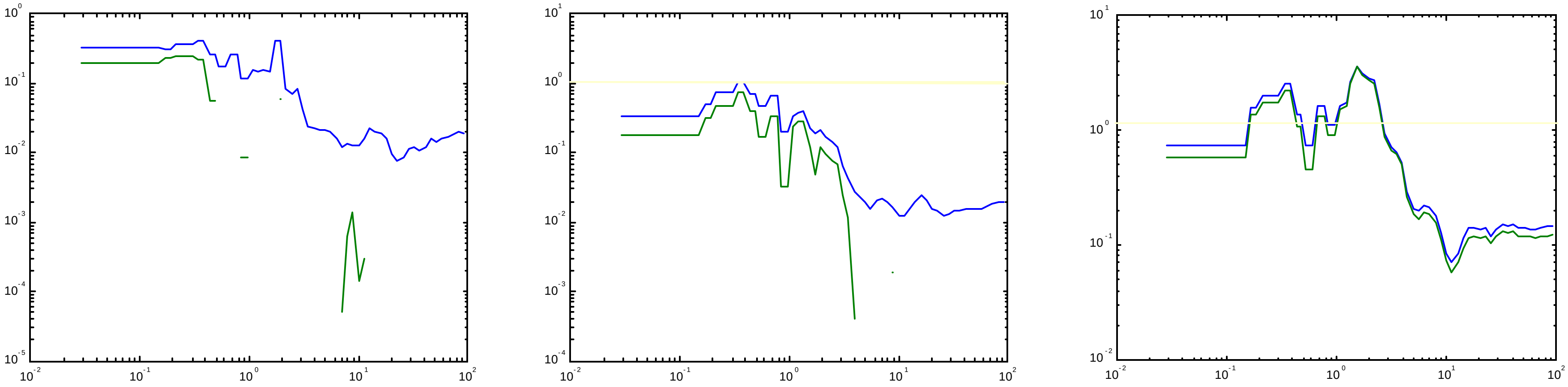


Controller 30 at #17 weight

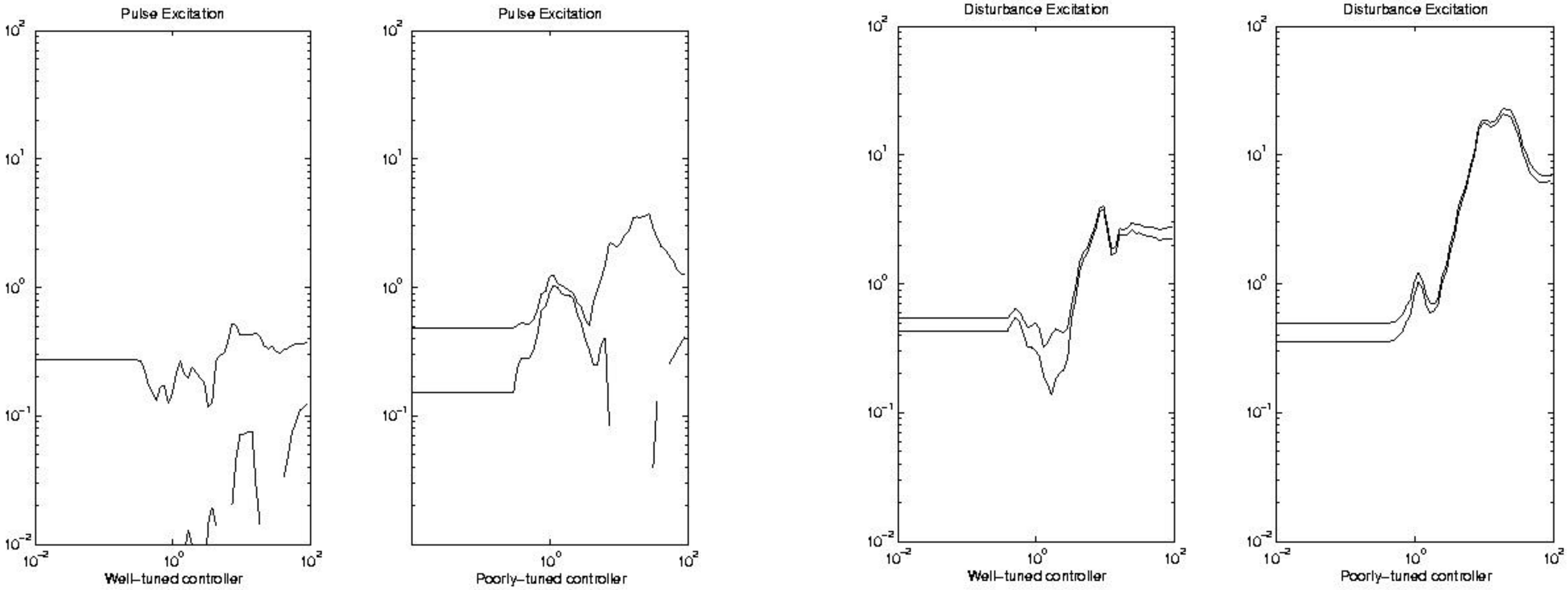


Simulated example: Diffusion furnace

- Controller designed for operation at 800 ^{o}C
- External excitation (below ID quality)
- Tests at 800 (nominal), 600 (worse but still OK), and with a known poor design



Simulated example: Diffusion furnace (cont.)



- Consistent results with low level excitation (three pulses)
- Large disturbance, no excitation: poor controller exhibits much larger violation of the test

Conclusions

- In general, consistent results are obtained with some excitation and good SNR
  - Lack of excitation often leads to inconclusive results
  - Yet, it is possible to reject a controller from single-operating-point data
  - Large disturbances: Visible differences, but harder to quantify
  - Disturbance bounds are important to avoid false alarms
- Simple computations, (could be recursive)
- Controller-in-the-loop and saturation concerns