Fast Model Predictive Control

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3 Apr 2012

Discussion Overview

- Models for Fast Model Predictive Control (MPC)
  - Selecting a Model for MPC
  - Subspace Identification (Linear model)
  - Parameter Estimation (Nonlinear model)
- Fast MPC Demonstrations with a 4 Tank Process
  - PID Control
  - Fast Linear MPC
  - Fast Nonlinear MPC
  - Comparison of Control Performance
- Next Generation Modeling and Control Platform

Selecting a Model for Predictive Control

- Many model forms
  - Linear vs. Non-linear
  - Steady state vs. Dynamic
  - Empirical vs. First Principles
- Select the simplest model
  - Accuracy requirements
    - Steady State Gain
    - Dynamics – Time to Steady State
  - Speed requirements
    - PID < Linear MPC < Nonlinear MPC

Continuous Form (SS_c)

$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$

Discrete Form (SS_d)

$$x[k+1] = A_d x[k] + B_d u[k]$$

$$y[k] = C_d x[k] + D_d u[k]$$

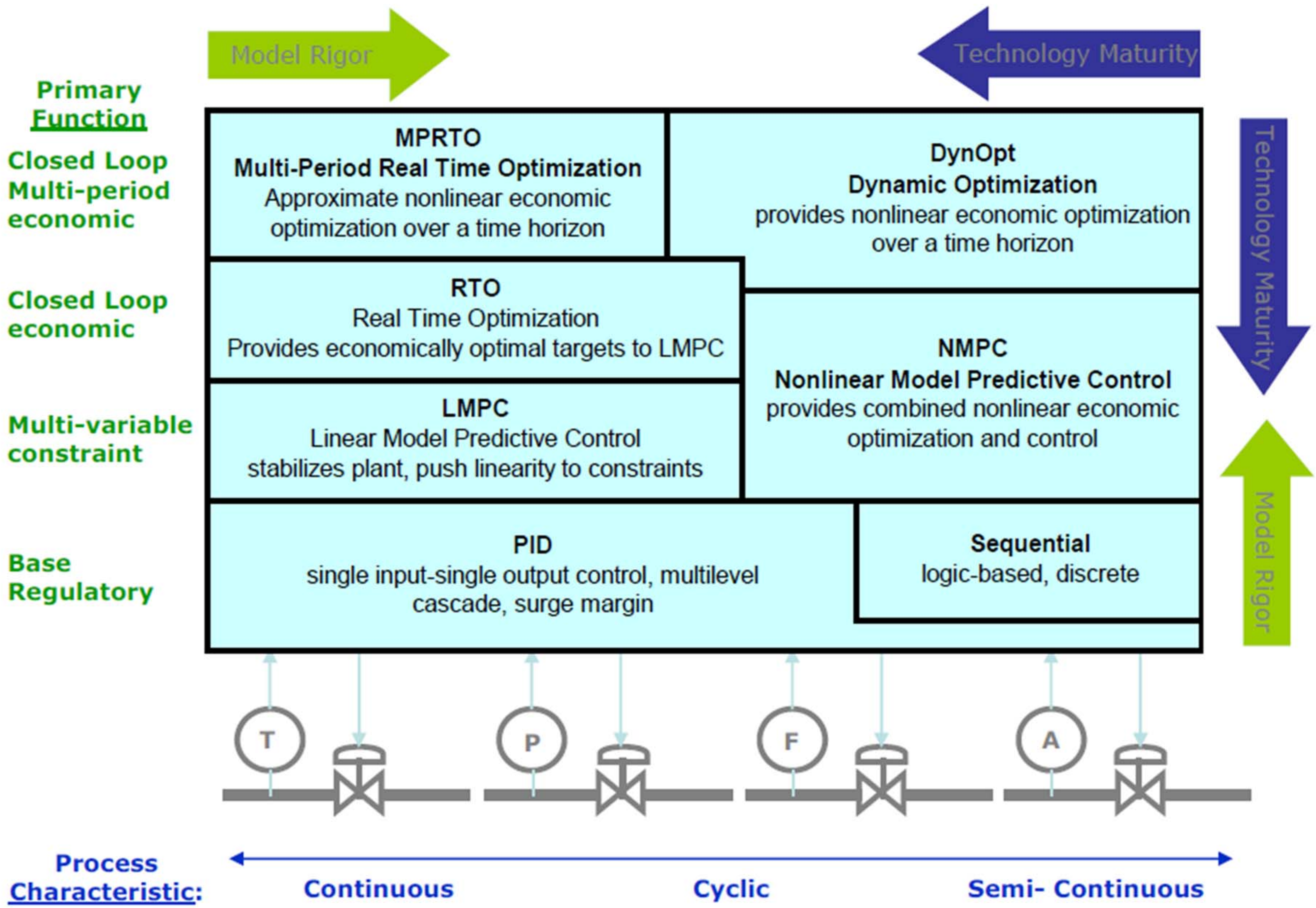
Nonlinear Model

$$0 = f\left(\dot{x}, x, u, p, d\right)$$

$$0 = g(x, u, p, d)$$

$$0 \le h(x, u, p, d)$$

Control Technology Overview



Soderstrom, Hedengren, and Yang, Advanced Process Control in ExxonMobil Chemical Company: Successes and Challenges, AIChE 2010.

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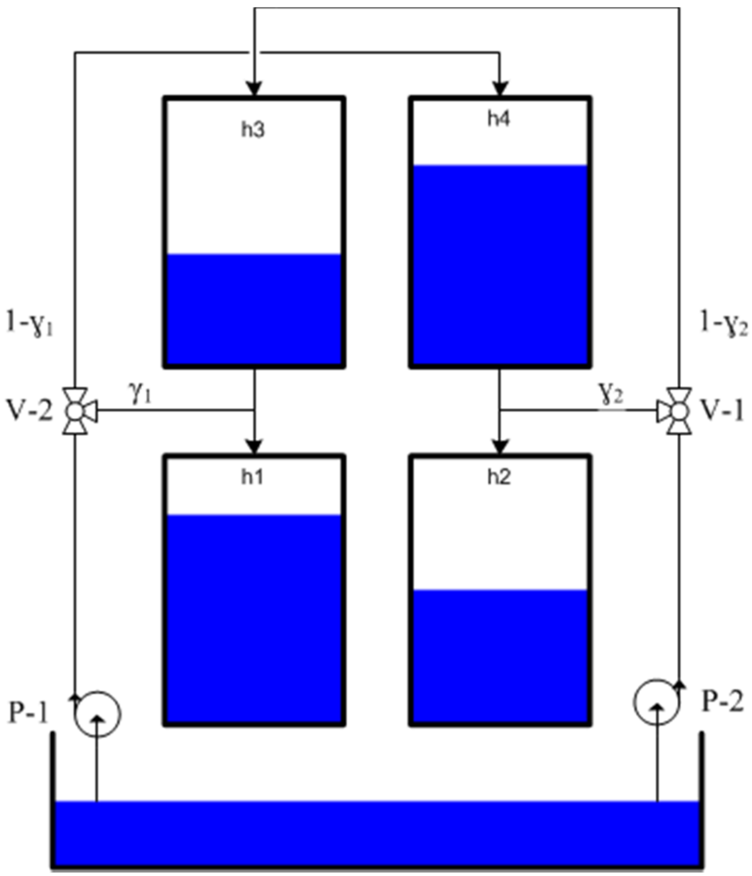
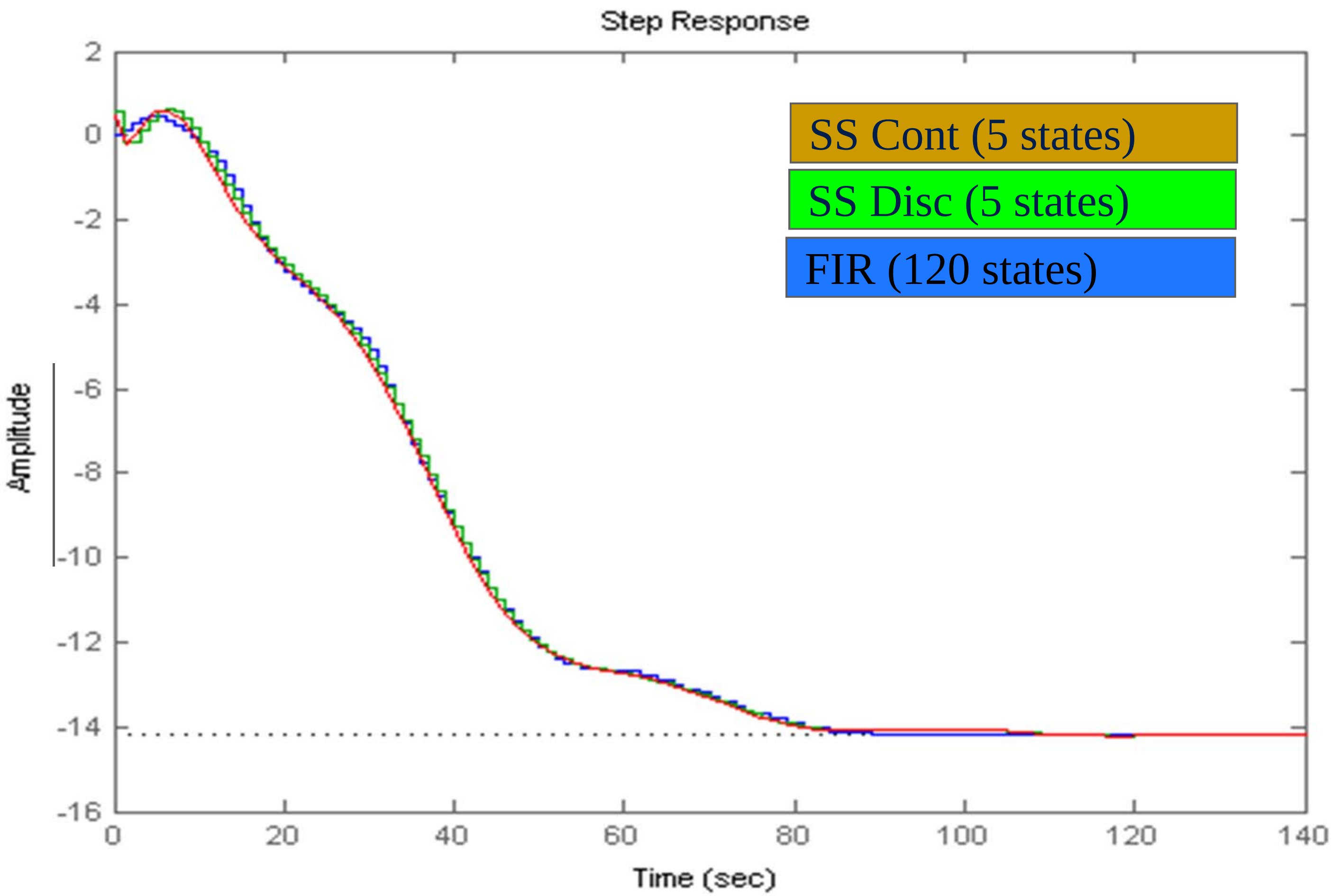
Multivariate 4 Tank Process

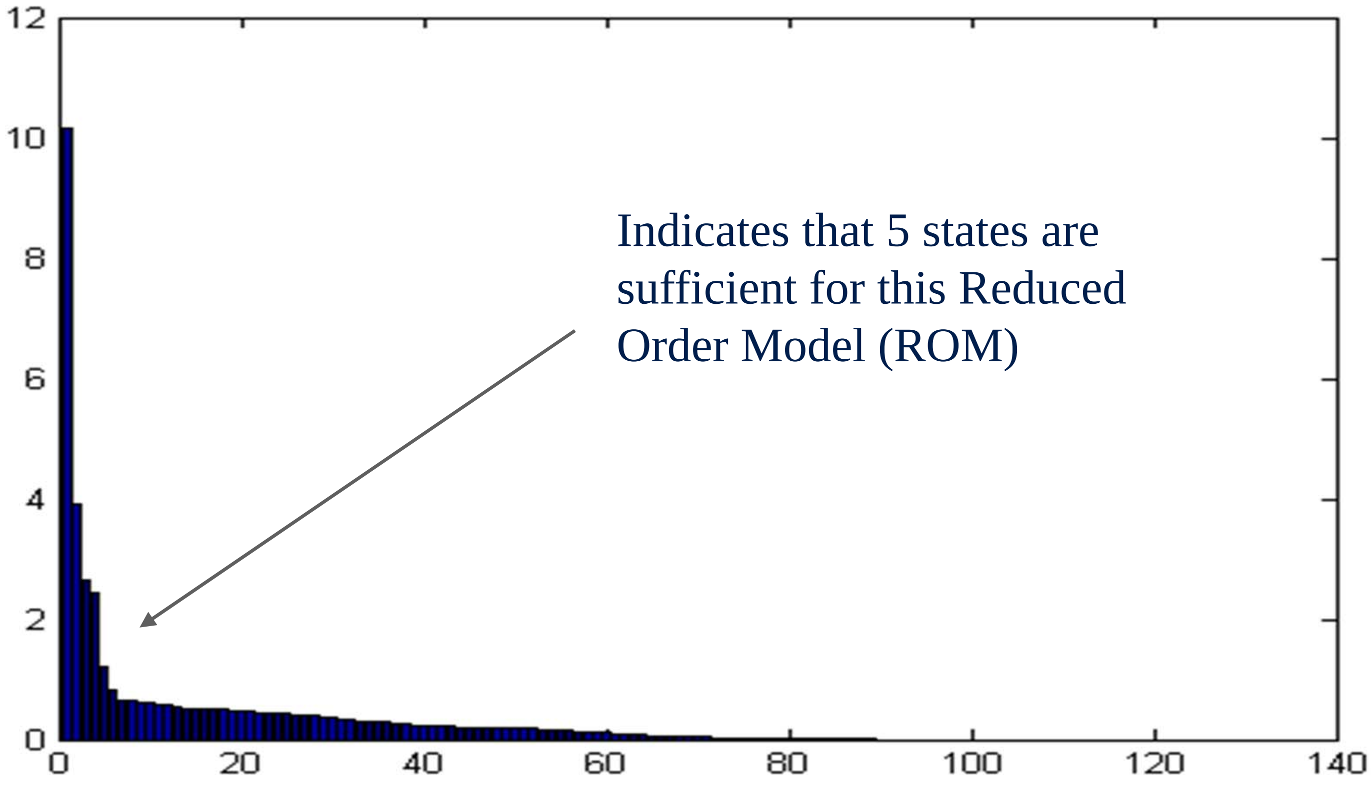
- Multiple Inputs (2)
  - Pump 1 and Pump 2 Voltages
- Multiple Outputs (2)
  - Height in Lower Tanks (1-2) Measured
- Characteristics
  - Highly coupled system
  - May exhibit inverse response
  - Split fractions (γ_1-γ_2) drastically change system dynamics and steady state behavior



Capture Essential Dynamics with State Space Models



Determine Number of States



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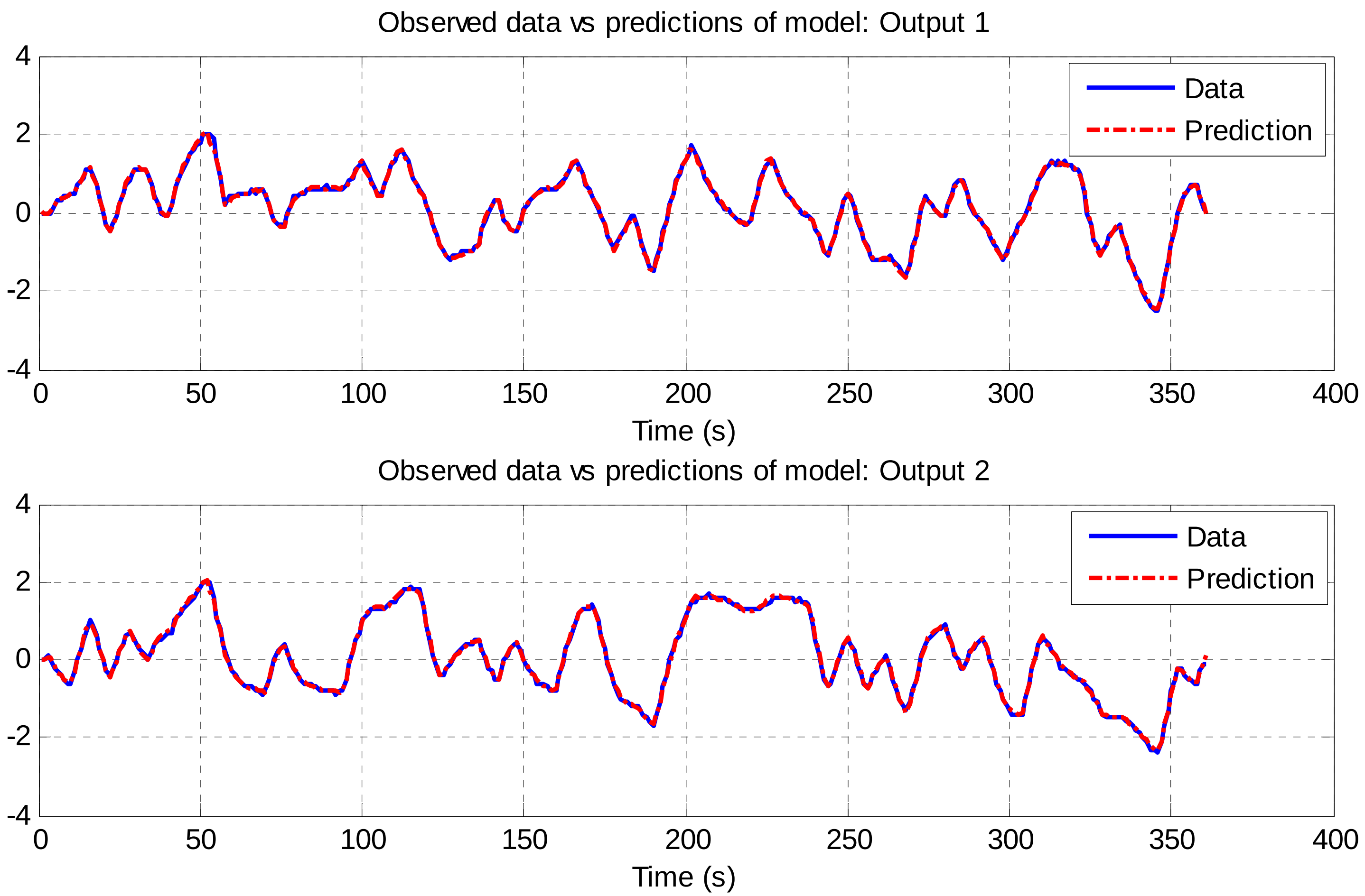
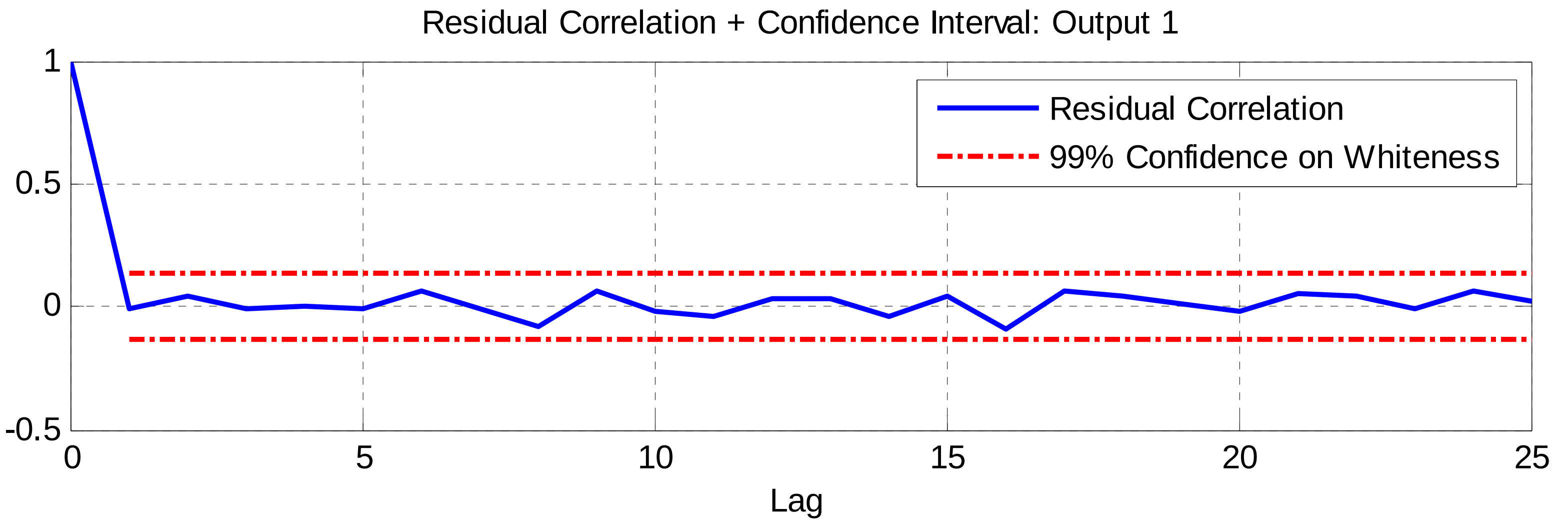
Linear Model Identification

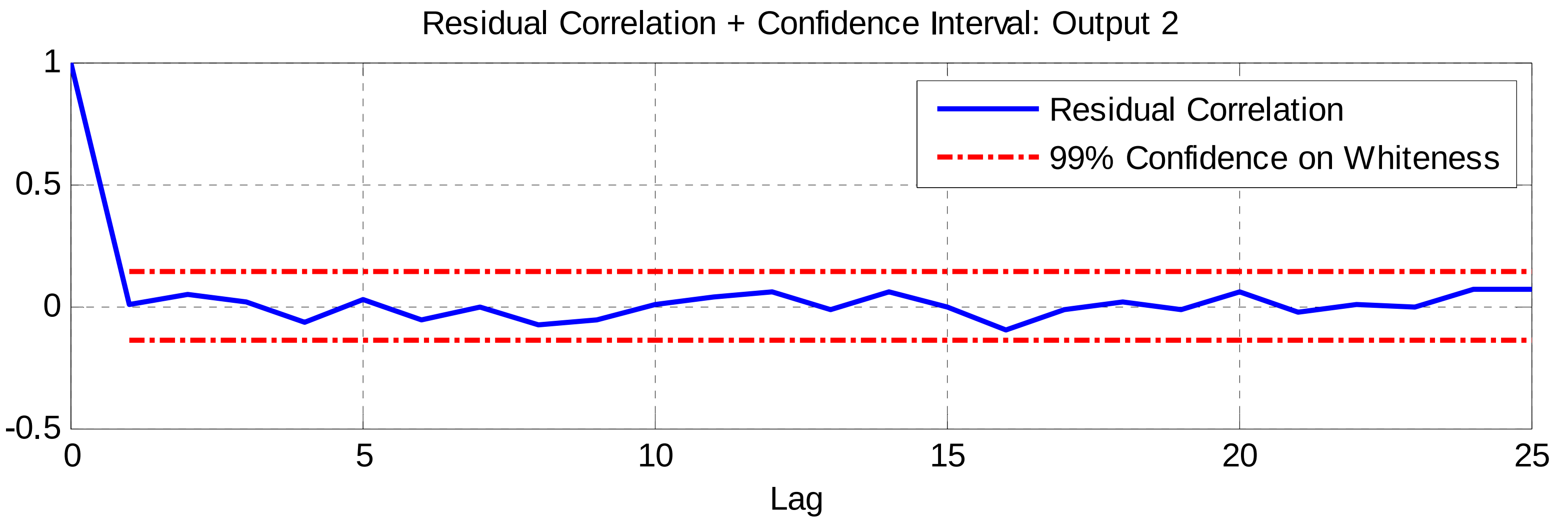
- Linear Empirical Model (ARX)



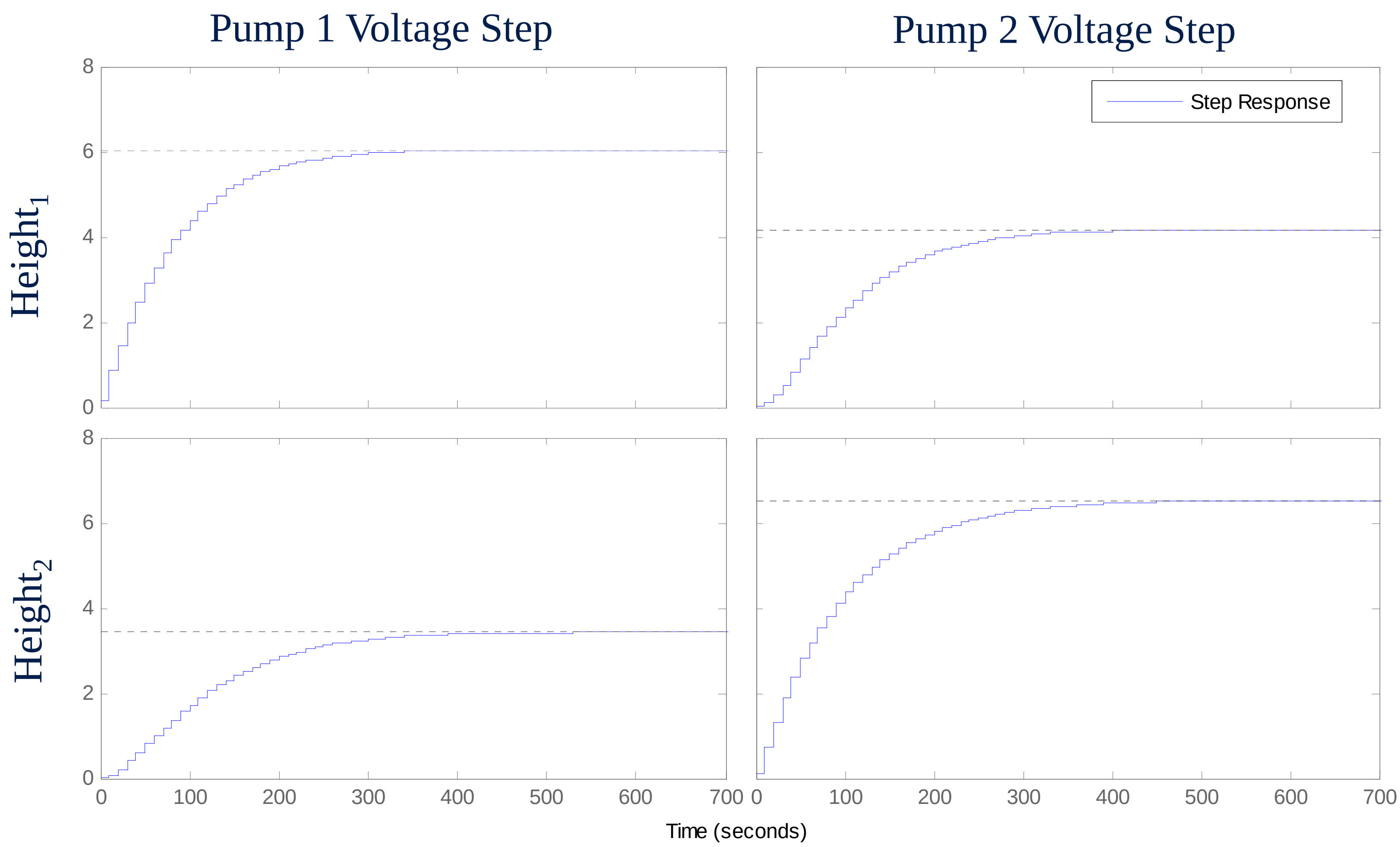
Correlation of Residuals

- Residual Whiteness Correlation





Model Step Response



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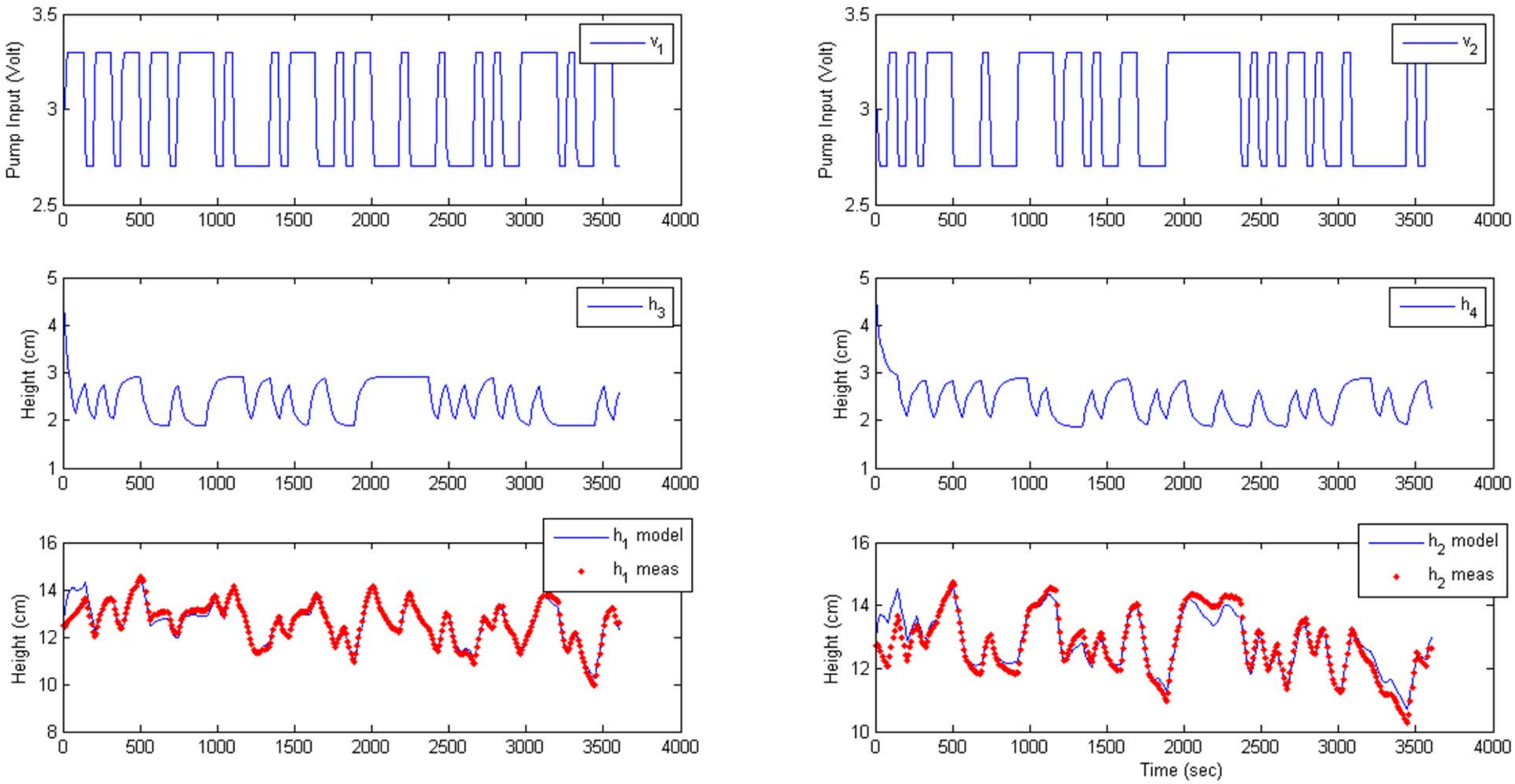
Nonlinear Parameter Estimation

- First Principles Model (DAE System)
  - Determine valve characterization, split fractions, outlet flow constants (6 parameters) using PRBS generated data



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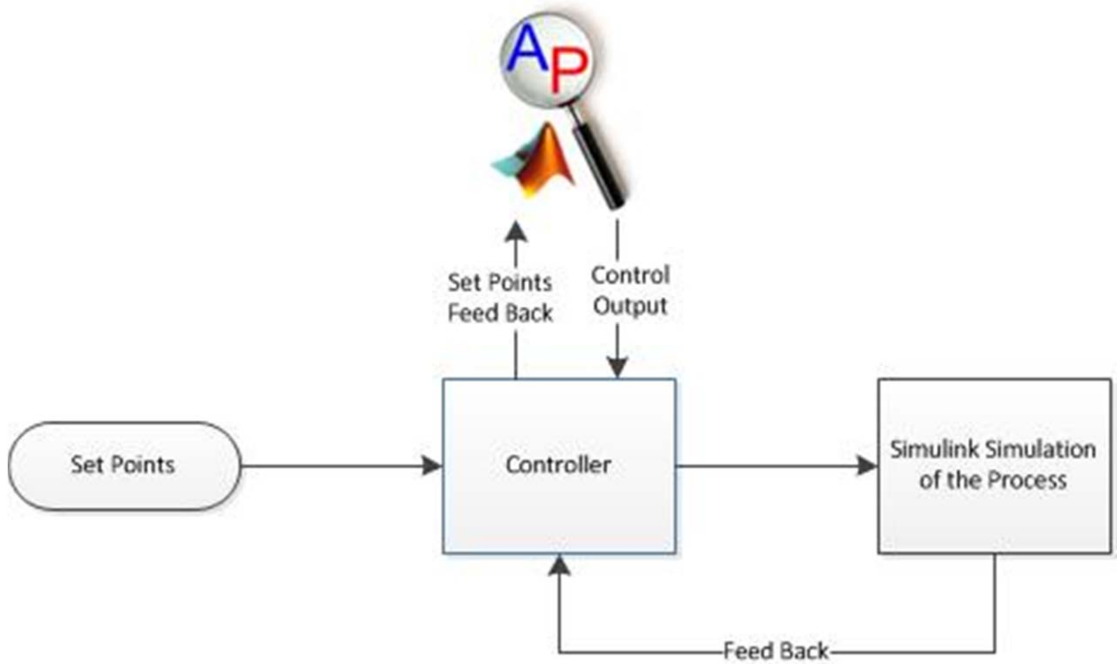
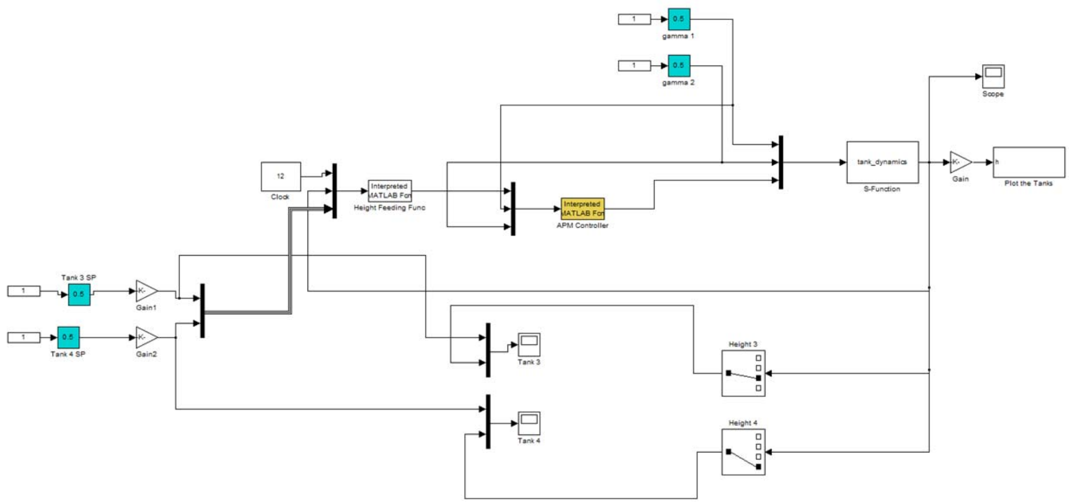
Nonlinear Control in Simulink

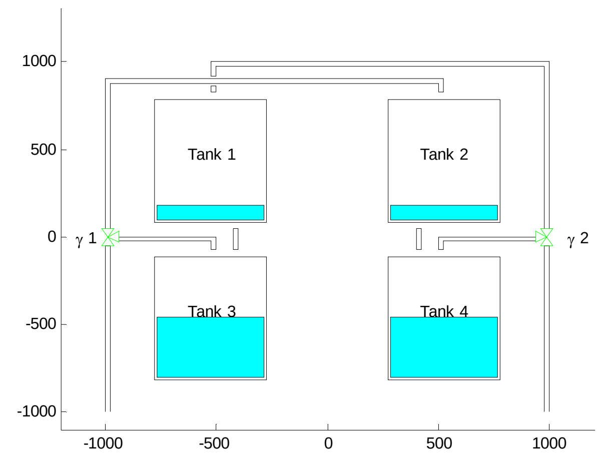
- Implemented APMonitor controller into a Simulink plant simulation
- The controller runs at 5 Hz



Nonlinear Control in Simulink

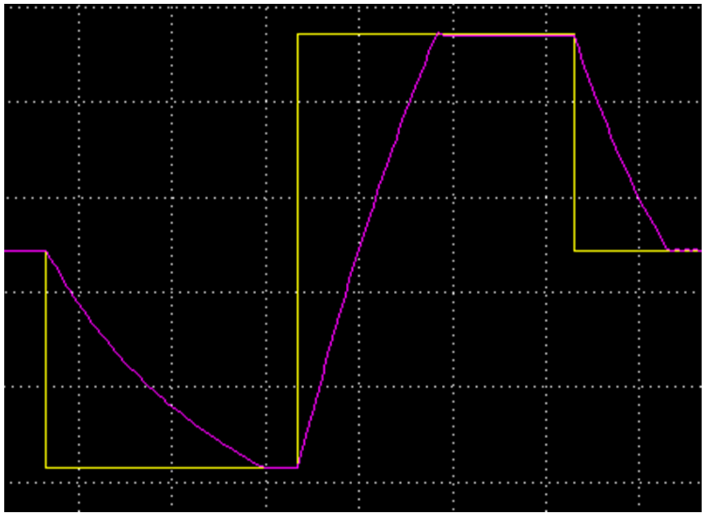
- APM Simulink Interface



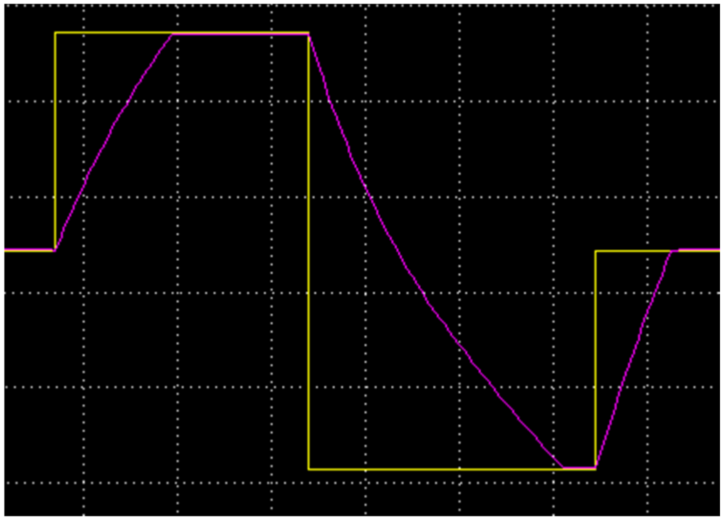


NLC (Nonlinear) Control

- Reverse doublet test results from Simulink simulation:



Tank 1 system response using NLC



Tank 2 system response using NLC

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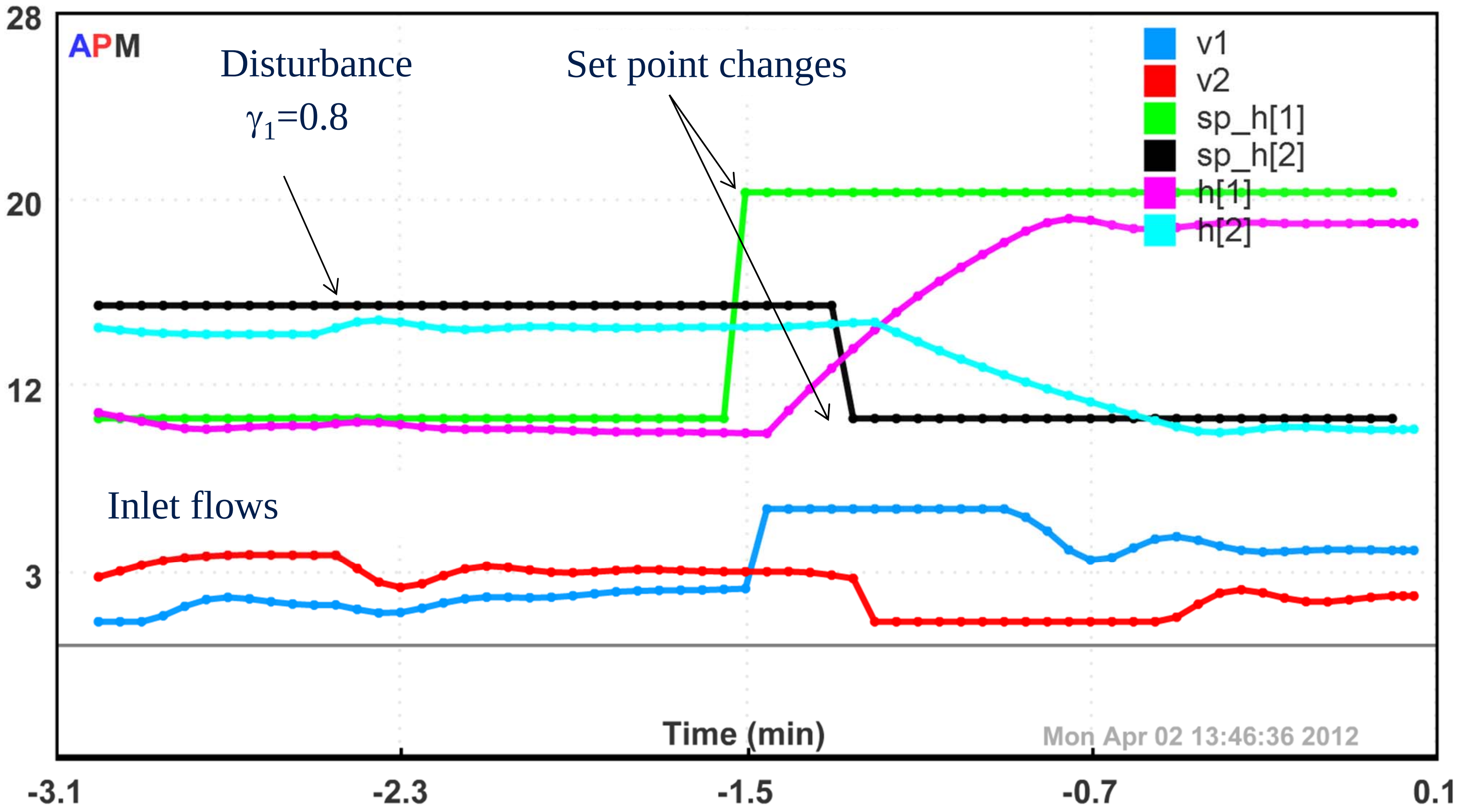
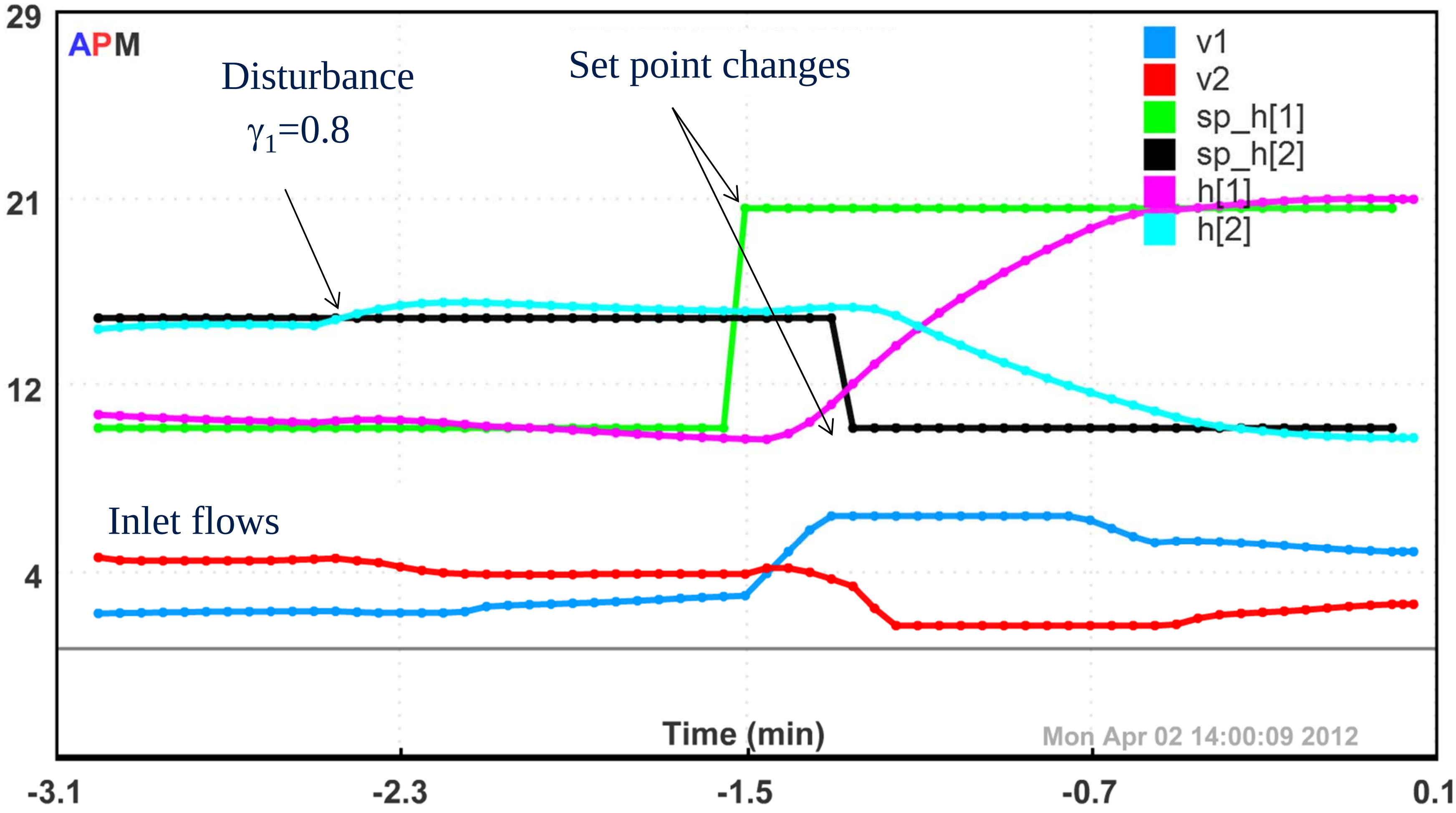
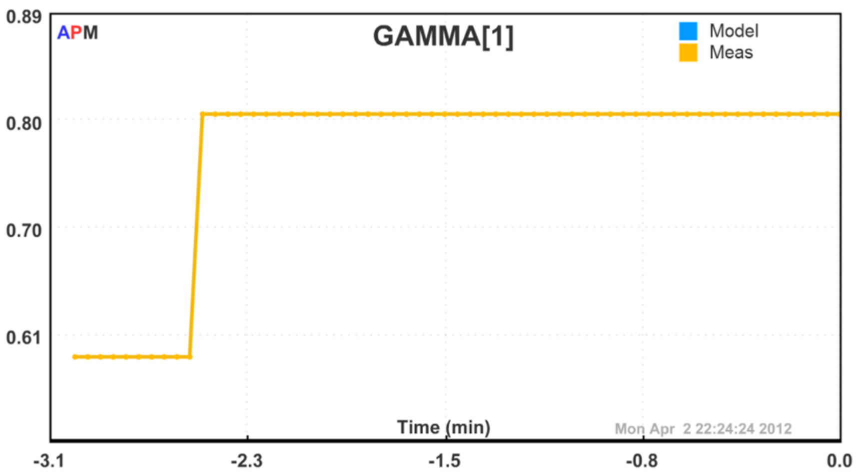
PID Control Performance

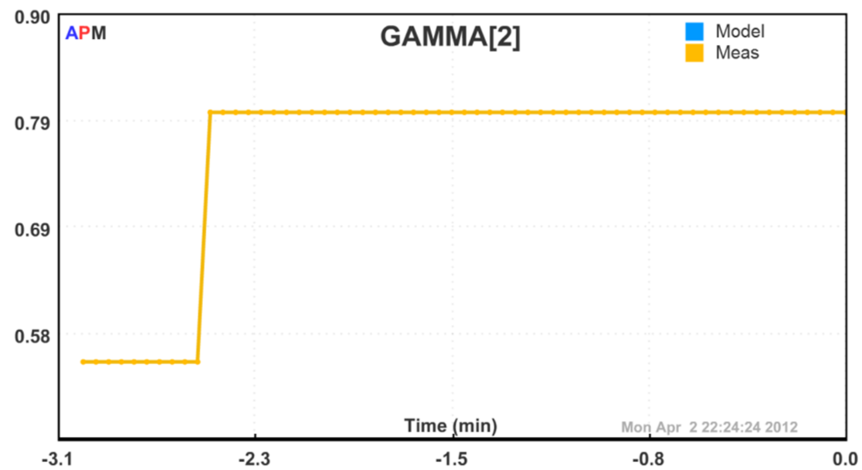


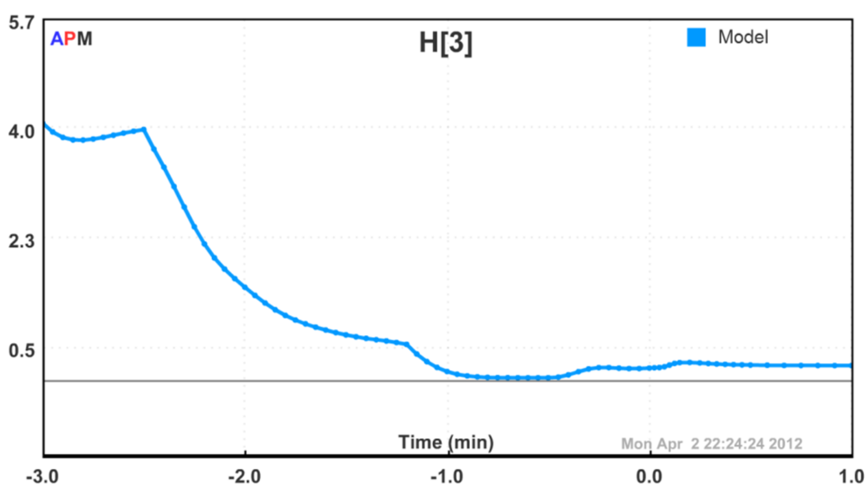
MPC (Linear) Control Performance

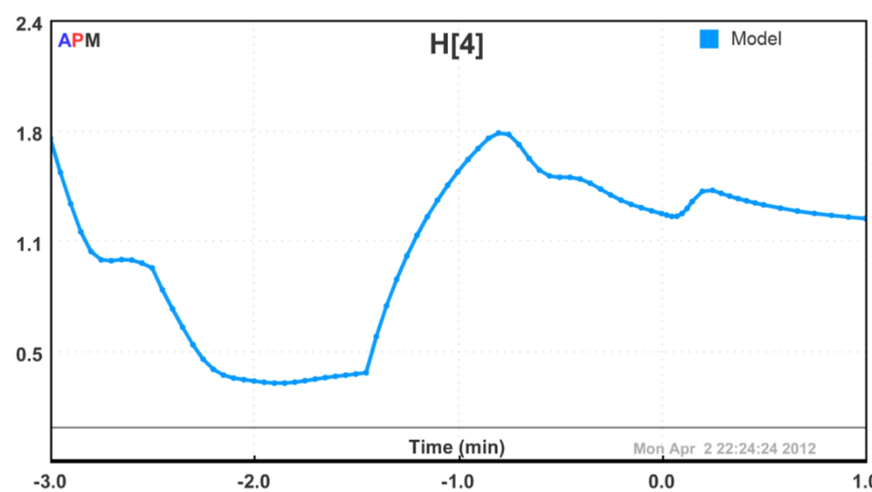


Trends of state variables and disturbances

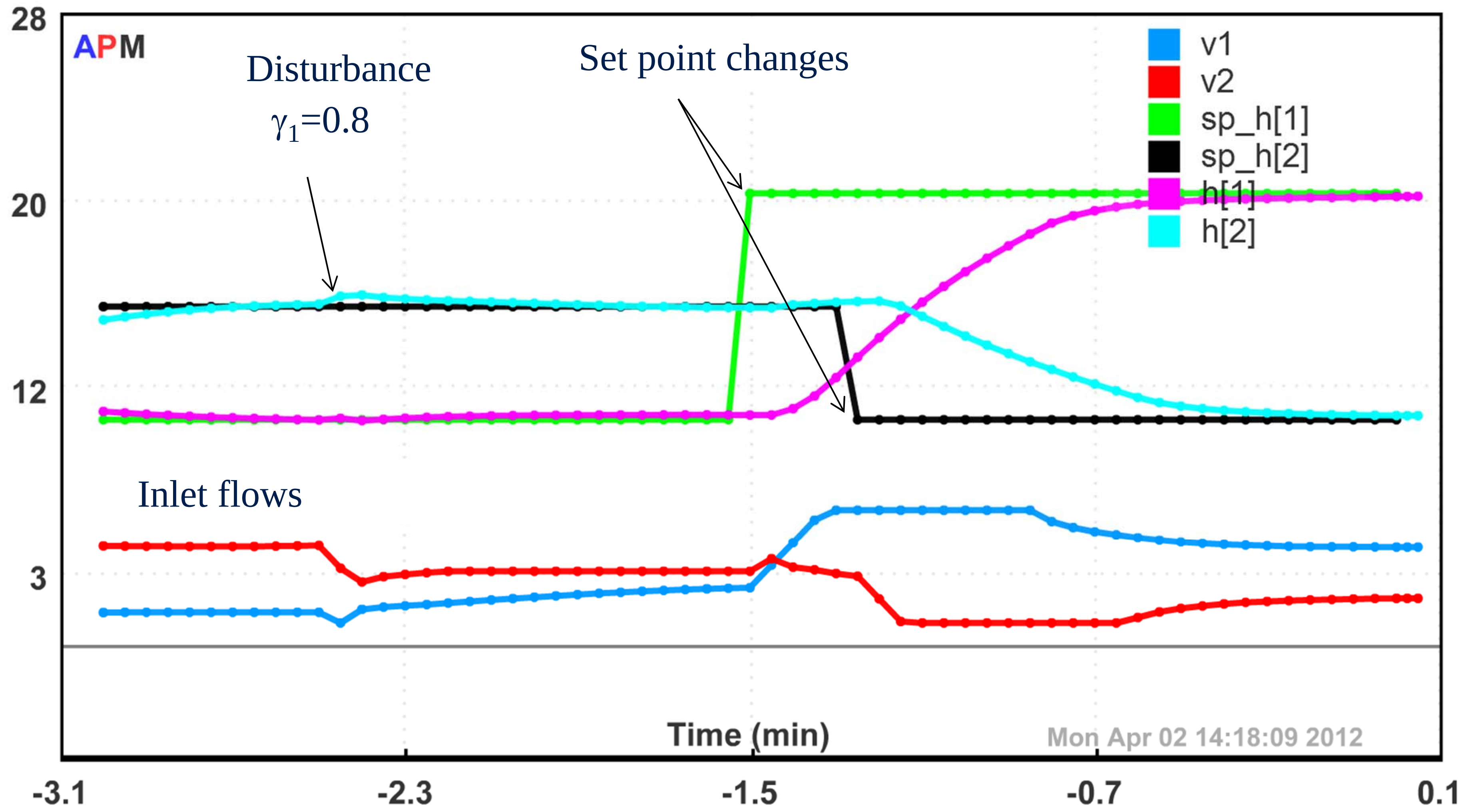




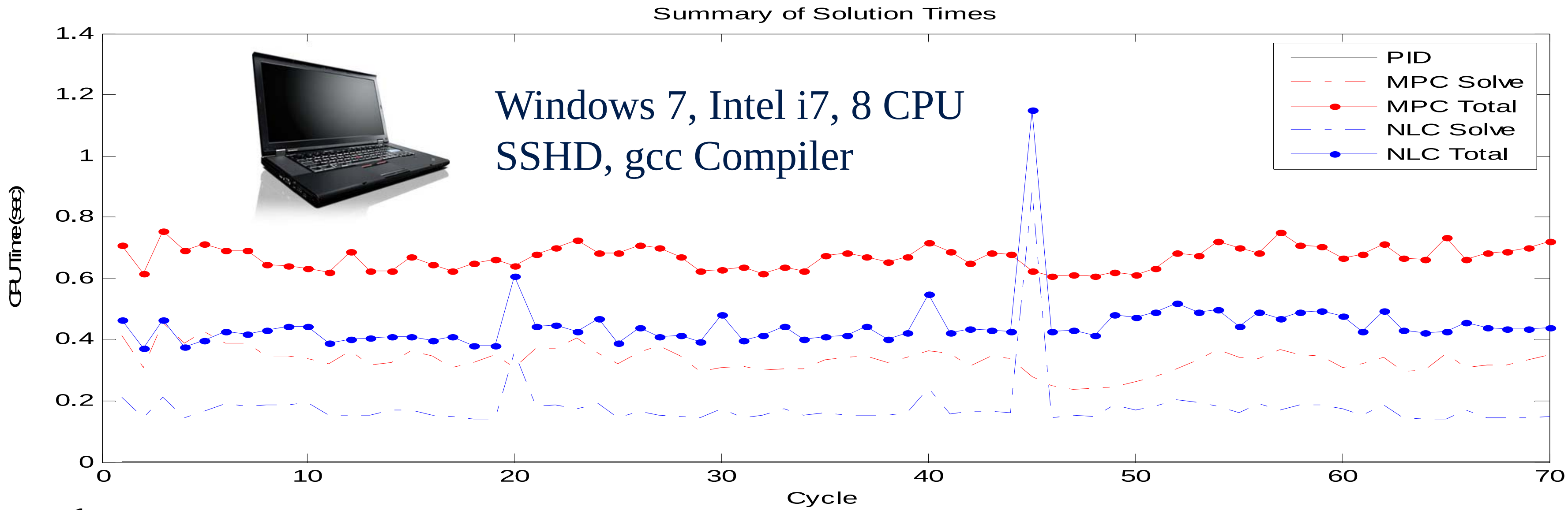


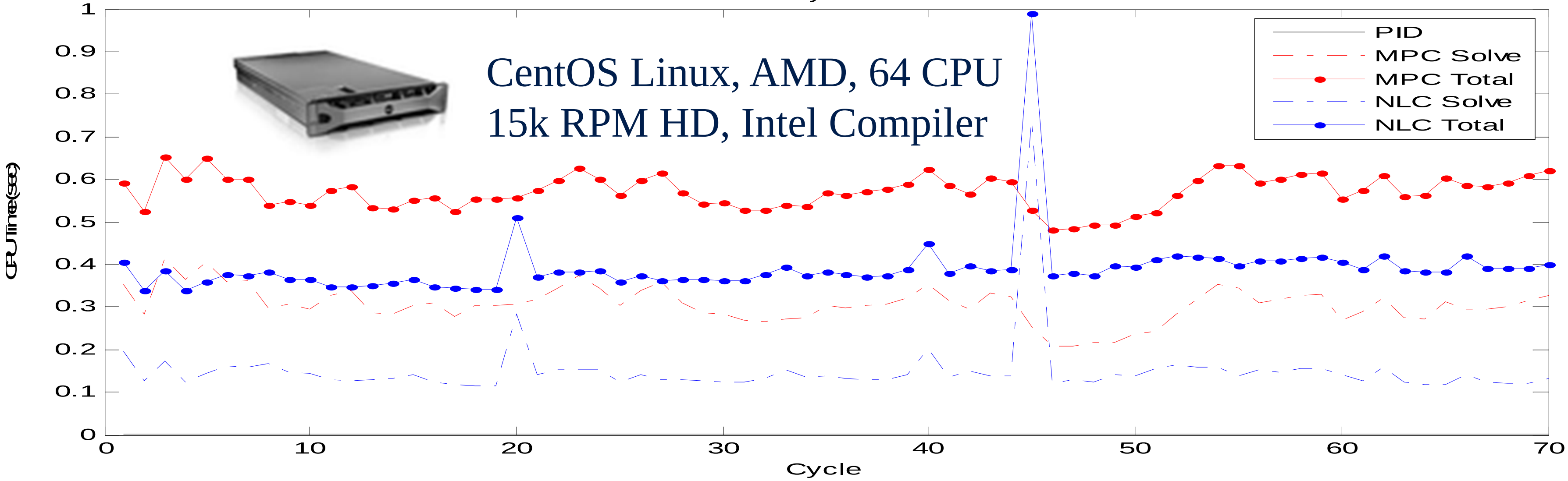


NLC (Nonlinear) Control Performance

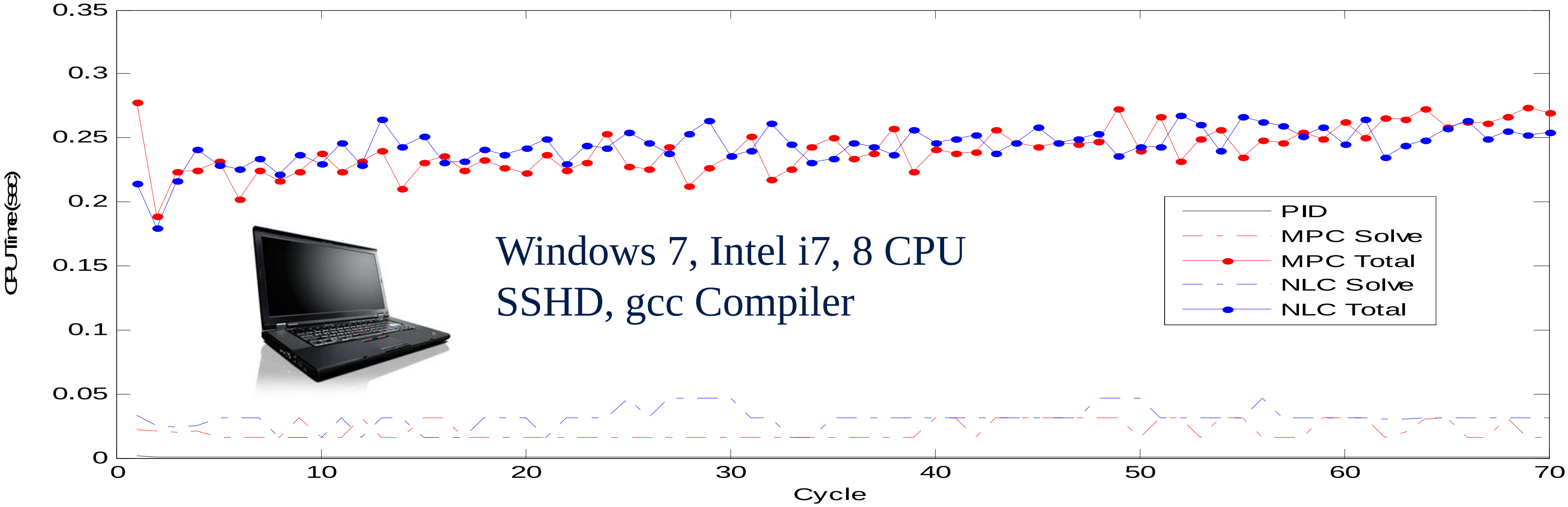


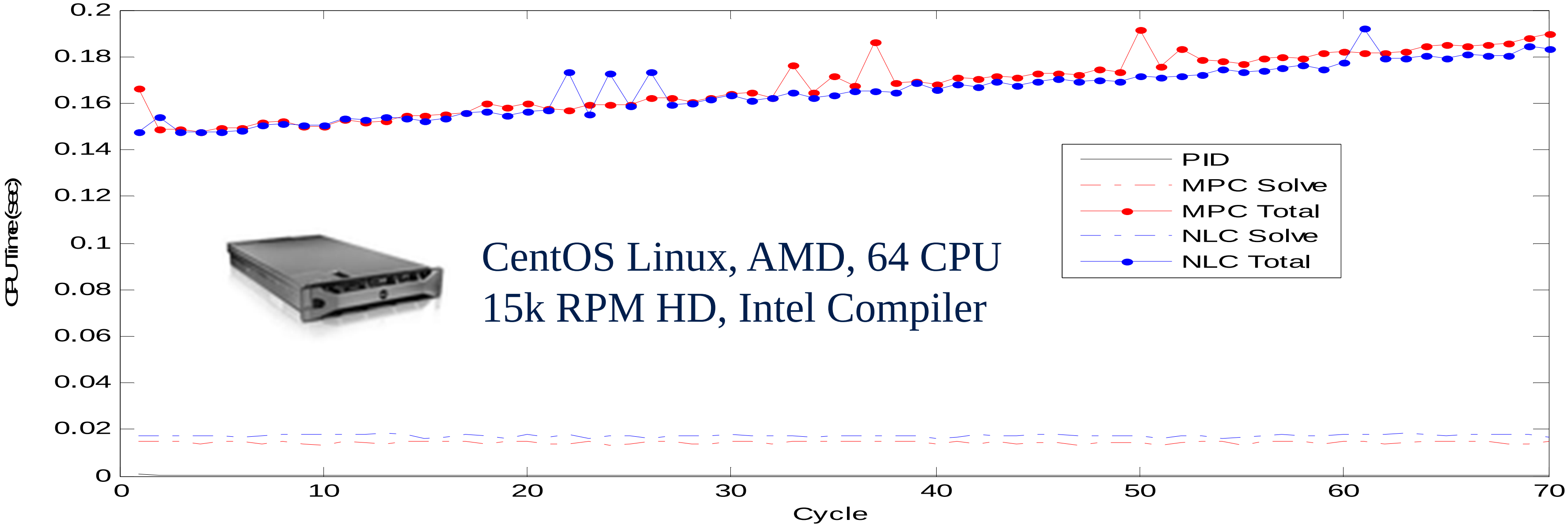
CPU Performance – Traditional MPC





CPU Performance – Optimized





Next Generation Control

- Next Generation Modeling and Control Platform?
  - Address usability issues
  - Integrated with Distributed Control System (DCS)
  - Operate efficiently and reliably
  - Use in base control as a replacement for PID control
  - Does storage and retrieval have a place?

- APM Software