Mechatronics :
Concepts and Applications

Outline

- Mechatronics
- Past and Present Research Results
- Undergraduate Program
- Directions for the Future
- Summary

What is Mechatronics?

- Synergistic combination of mechanics, electronics, microprocessors and control engineering
  - Like concurrent engineering
  - Does not take advantage of inherent uniqueness available
- Control of complex electro-mechanical systems
  - Rethinking of machine component design by use of mechanics, electronics and computation
  - Allows more reconfigurablility

What is Mechatronics

- Design example: timing belt in automobile
- Timing belt mechanically synchronizes and supervises operation
- Mechatronics: replace timing belt with software
- Allows reconfigurability online

What is Mechatronics

- Second example: Active suspension
- Design of suspension to achieve different characteristics under different operating environments
- Demonstrates fundamental trade-offs

What is Mechatronics

- Low tech, low cost, low performance: pure mechanical elements: spring shock absorber
  - Can use dynamic systems to find coefficients via time or frequency domain
- mid tech, cost, performance: electronics: op amps, RLC circuits, hydraulic actuators
  - Typically achieve two operating regimes, e.g. highway vs off-road
- High tech, cost , performance: microprocessor-based online adjustment of parameters
  - Infinitely adjustable performance

Research Projects

- Discrete Sliding Mode Control with Applications
- Helicopter Flight Control
- OHS Aircraft Flight Control
- Magnetic Bearings in Papermaking Systems
- Robust Control for Marginally stable systems
- Process Control and System ID
- Controller Architecture

Theme of research

- Control of
  - Uncertain
  - Nonlinear
  - Time-varying
  - Industrially relevant
  - Electro-mechanical systems
- This is control applications side of mechatronics
- Involves sensor, actuator, controller design

What is control?

- Nominal performance
  - Servo tracking
  - Disturbance rejection
- Low sensitivity
  - Minimal effects of unknown aspects
  - Non-time-varying

Helicopter Flight Control

- Model-following vs. stability
  - Conflicting Multi-objective
- Controller Optimization
- Order reduction
- System validation

Helicopter Flight Control

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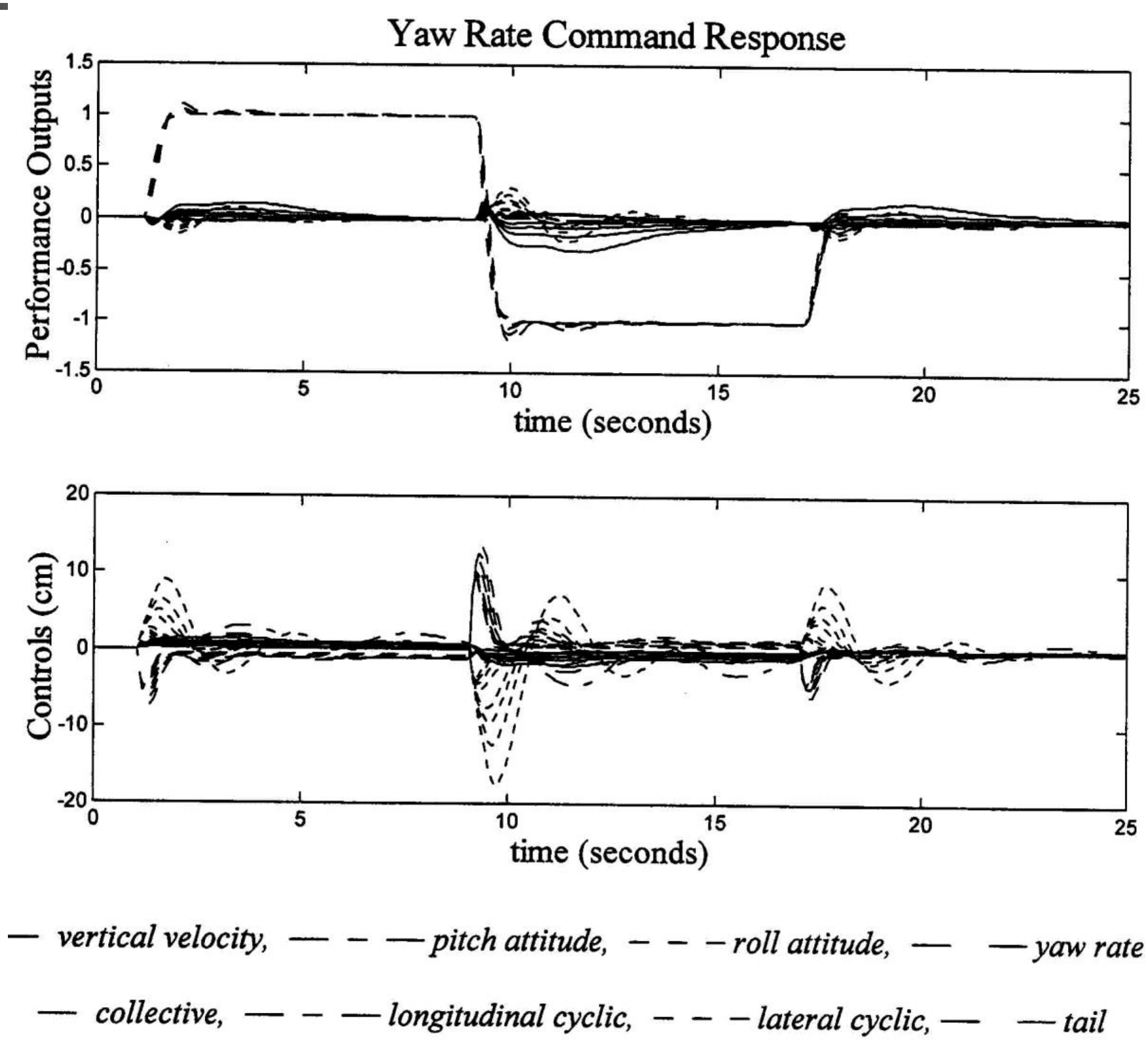


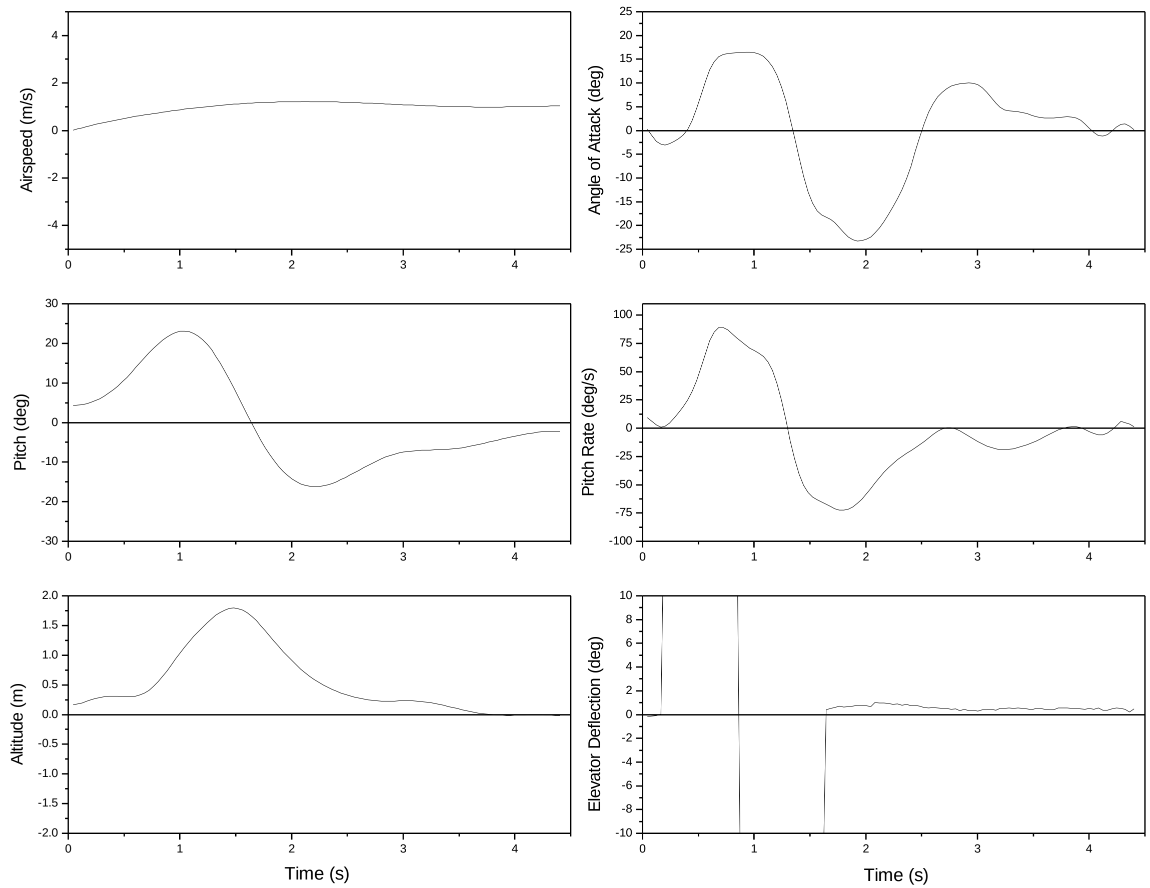
OHS Aircraft Flight Control

- Outboard Horizontal Stabilizer
- Non-intuitive to fly
- Developed sensors and actuators
- Model identification and validation
- Gain-scheduled adaptive control
- Reconfigurable controller based upon feedback available

OHS Aircraft

15 m/s

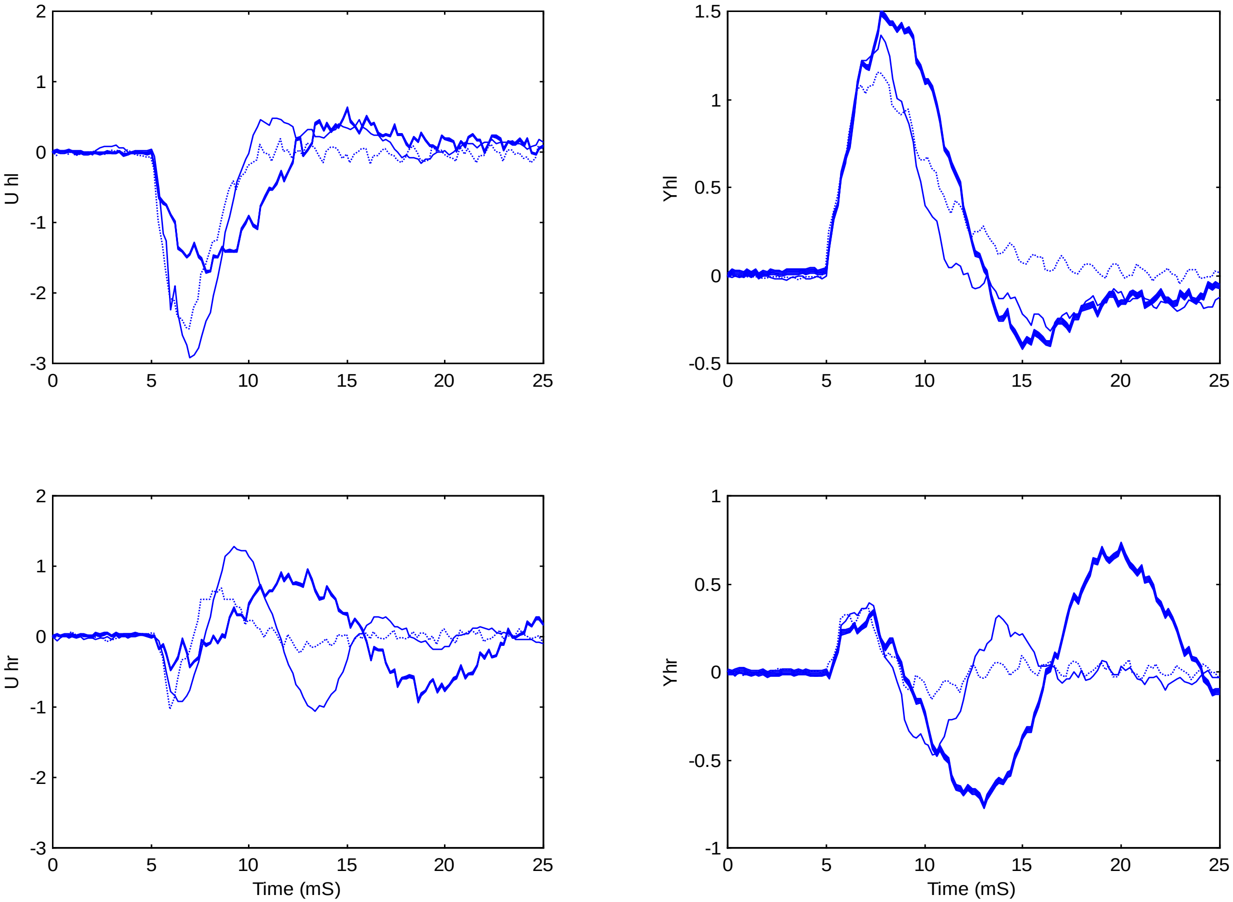
20 m/s



Magnetic Bearings in Papermaking Systems

- System identification for magnetic bearings
- Nonlinear, unstable system
- Closed loop modeling
- Control Design using Sliding Mode methods and state estimators
- Servo-Control of shaft position

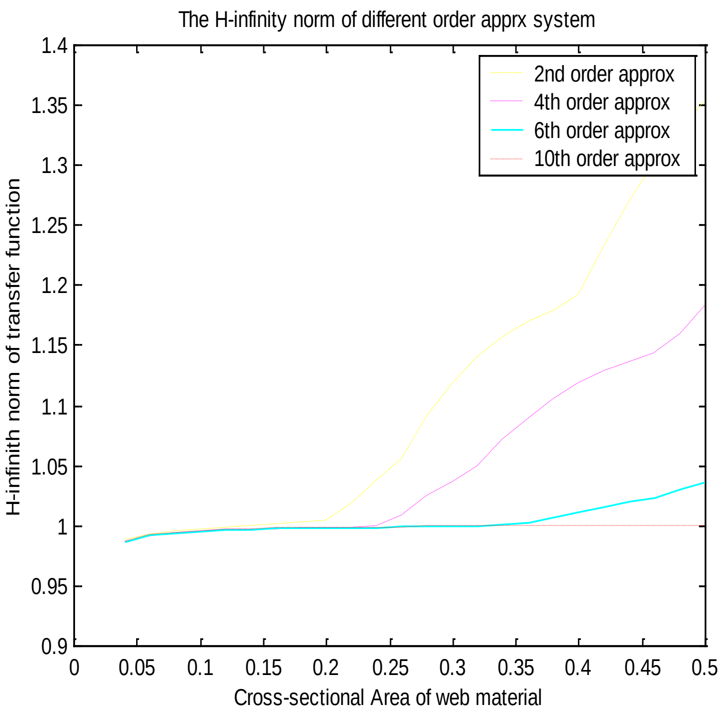
Magnetic Bearings

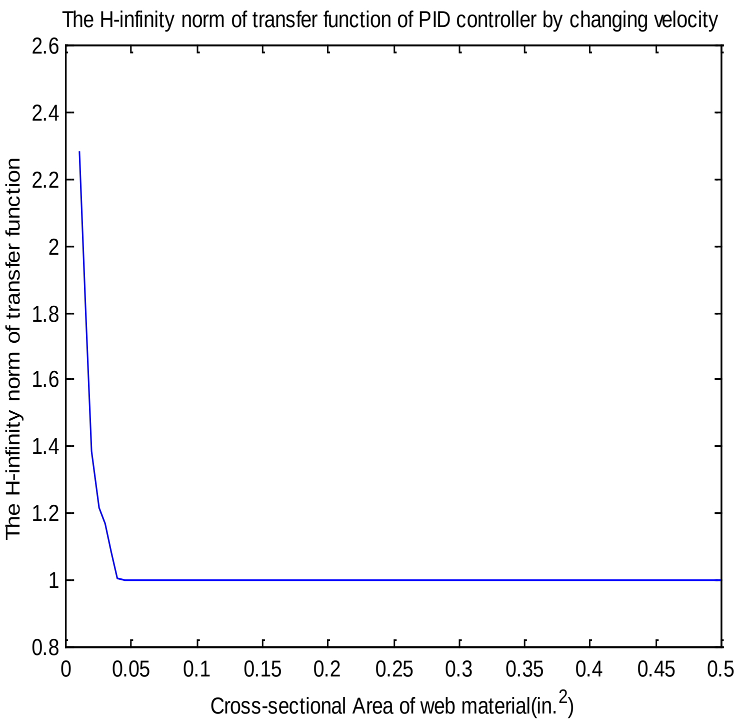


Magnetic Bearings in Papermaking Systems

- Papermaking system modeling
- Use of mag bearings for tension control actuation and model development
- Control Design and implementation issues
- Compare performance with standard roller torque control

Papermaking Tension Control





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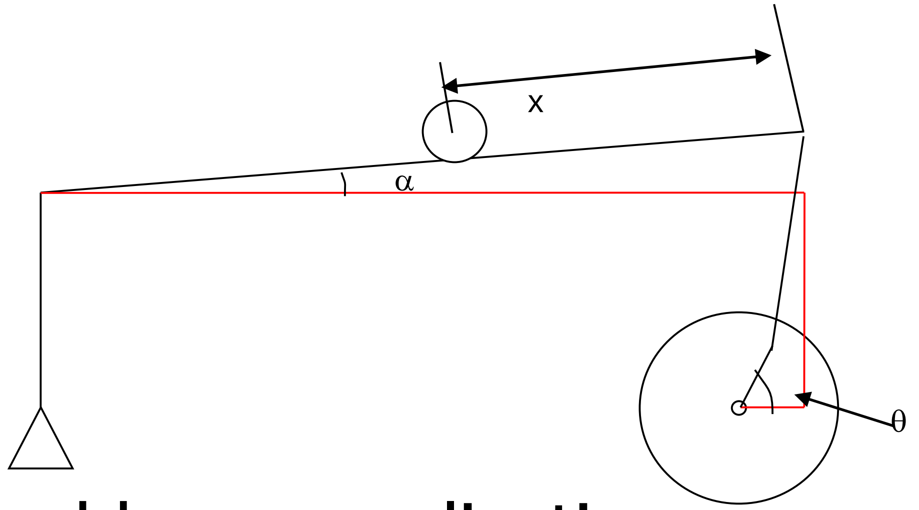
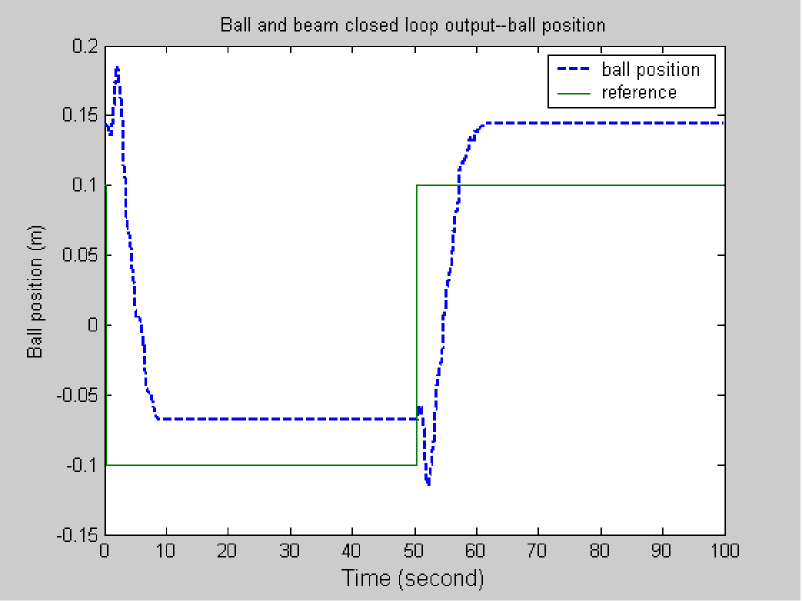
Robust Control via Q-parameterization



- Ball and beam application
- Stability margin optimization: Nevanlinna-Pick interpolation

Experimental Results

- Large lag
- Non-minimum phase behaviour
- Friction, hard limits



Robust Stability Margin

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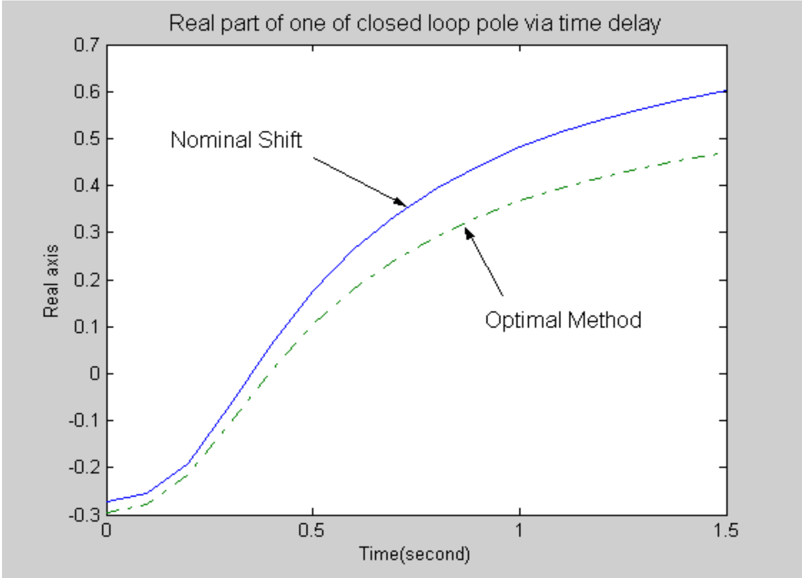
Delay	Nominal	Optimal
0	-0.27	-0.30
0.1	-0.26	-0.28
0.2	-0.19	-0.22
0.3	-0.07	-0.11
0.4	0.06	0.01
0.5	0.17	0.10
0.6	0.26	0.18
0.7	0.34	0.24
0.8	0.39	0.29
0.9	0.44	0.33
1	0.48	0.37
1.1	0.51	0.40
1.2	0.54	0.42
1.3	0.56	0.44
1.4	0.58	0.46
1.5	0.60	0.47

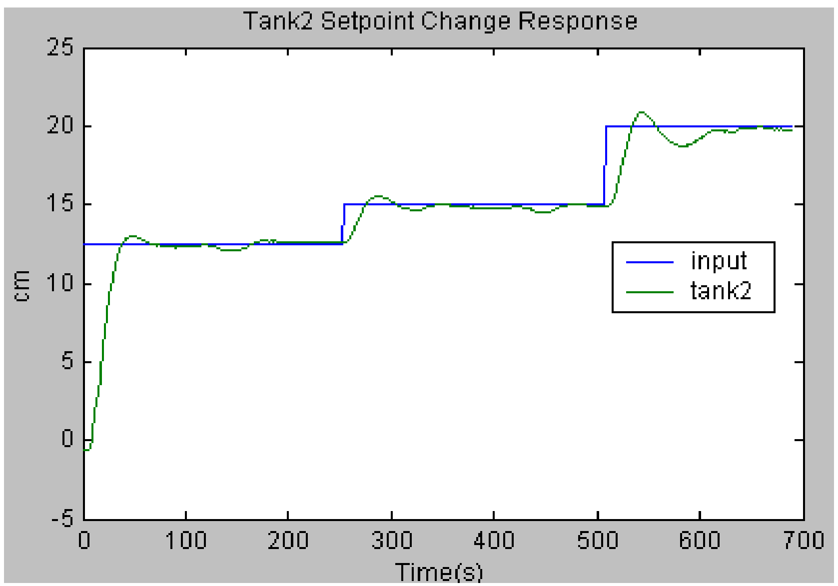


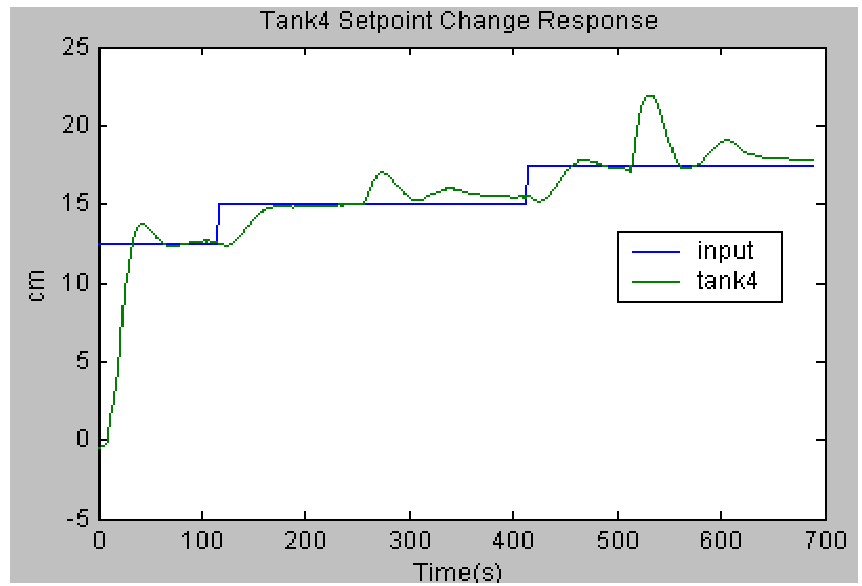
Control Techniques

- Classic PI control
- Internal Model Control (IMC)
- Model Predictive Control (MPC)
- Linear Quadratic Regulator (LQR) Optimal Control

MPC Control Results

Different set points changes to test MPC controller performance





Tank2 response

Tank4 response

Performance Comparison

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Parameters \ Controllers	PI	IMC	MPC	LQR
M_P(%)	4	20	5	32
t_s (sec)	31	99	50	210
ss e(%)	1.5	0	0	0
$\|\|e\|\|_2$	2.7	0.8	0.45	0.3
$\|\|e\|\|_\infty$	0.2	0.08	0.05	0.05
t_{rc}(sec)	34	102	47	76

Controller Architecture

- Given conflicting and redundant information
- Design controller with best practical behaviour
  - Good nominal performance
  - Robust stability
  - Implementable

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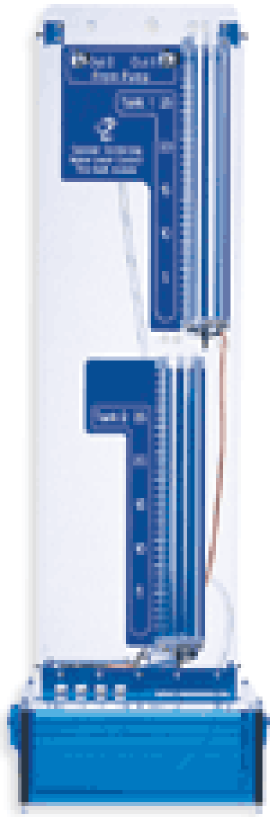
Undergraduate Program: Mechatronics Lab with Applications

- Developed lab environment for teaching and research
- Two courses: - linear systems, - prototyping
- Hands-on work in:
  - modeling
  - system identification
  - Sampled-data systems
  - Optical encoding
  - State estimation
  - Control design

Mechatronics Lab with Applications

- Multivariable fluid flow control system
  - Two-input-two-outputs
  - Variable dynamics
  - Model Predictive Control
  - Chemical Process Emulation

Fluid Flow Control



Quanser Product

Mechatronics Lab with Applications

- Ball and Beam system
  - Hierarchical control system
    - Motor position servo
    - Ball position
  - Solve via Q-parameterization
    - Robust stability and optimal nominal performance

Ball and Beam System

Quanser Product

Mechatronics Lab with Applications

- Heat Flow Apparatus
  - Unique design
  - Varying deadtime for challenging control
- Demonstrate industrial control schemes
  - PID controllers
  - Deadtime compensators

Directions for the Future

- Robust Performance
  - robust stability and nominal performance simultaneously guaranteed
- Multiobjective Control Design
  - Systems that meet conflicting, and disparate objectives
- Performance evaluation for soft measures
  - Fuzzy systems

- Bottom line: Mechatronics

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Summary

- Control applications in electro-mechanical systems
- Emphasis on usability
- Complex problems from simple systems
- Undergraduate program: hands-on learning and dealing with systems form user to end-effector