Experiments for a Multi-disciplinary Industrial Controls Course

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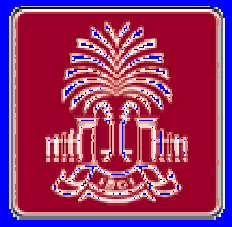


UNIVERSITY OF SOUTH CAROLINA

Outline

1. Goals and Motivation
2. Course Outline
3. Experiments
4. Bonus: Lego ChE system
5. Conclusions

Goals

- Introduce undergraduate students to intermediate theoretical concepts in process dynamics and control
- Demonstrate to students applications of control theory and methods on industrial type systems
- Try to keep course level such that the only prerequisite was differential equations, making the course approachable by ME, EE, and CHE students

Motivation

- Hands-on experience needed to reinforce lecture topics and provide frame of reference
- Process control can be very theoretical, needs real motivation and demonstration of complex topics
- Process control is well-suited to multi-disciplinary approach, ME + EE + CHE
- Good setting for group based learning
- Students taking industrial positions will work with or near automation systems

Course Outline

- Programmable Logic Control
- Review of SISO dynamics / control (Laplace transforms)
- State-space dynamic modeling of systems
- Discrete time transfer functions and modeling
- Feedforward control, Internal Model Control (IMC)
- Model Predictive Control (MPC)
- Basic state estimation and parameter estimation

Experiments

- PLC programming using ladder logic
- Inverted pendulum system
- Real-time control / Real-time simulation
- Multivariable pressure tank system
- Industrial DCS system

PLC Programming

- 6 digital inputs, 6 digital outputs, 12VDC.
- Cost < $200 each
- 4k EPROM Chip
- Eware32 – windows based
  - Downloadable freeware
- RS232 full duplex serial port interface
- Students had take-home kits to work with

PLC Programming Topics

- Boolean Logic
- Truth Tables
- Reducing Boolean Expressions using Karnaugh Maps
- PLC Hardware and Software Components
- Ladder Logic Diagrams
- Sequence Diagrams
- Timers and Counters

Inverted Pendulum

- Open-loop unstable System
- Demonstrate effects of sampling times
- LQR full state feedback control
- Motivates state estimation

Real-Time Control

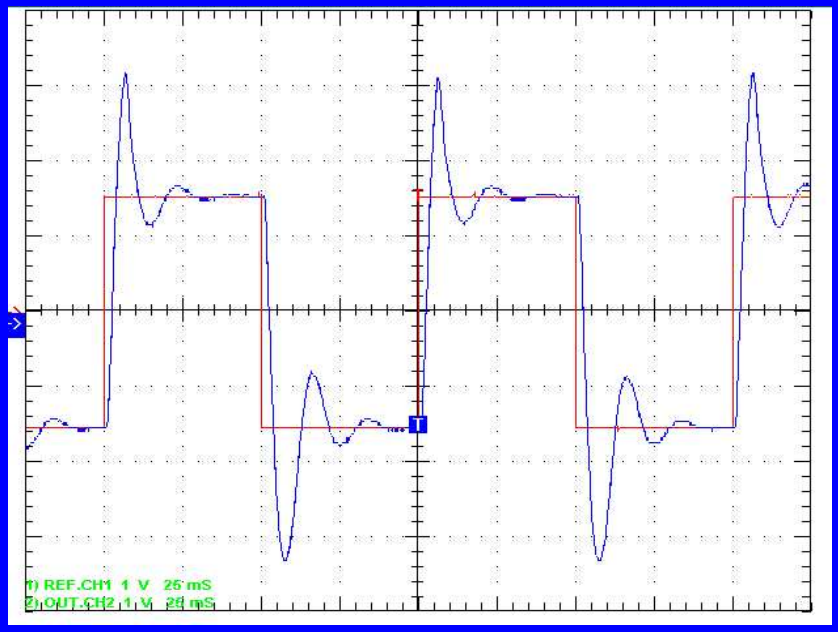
- Dynamic simulation using Linux Realtime OS
- Students develop a simple real-time controller prototype using:
  - dSpace hardware controller
  - Matlab Real-time Workshop toolbox
- Real-time controller programmed then tested and evaluated in loop with real-time simulation

Real-Time Control

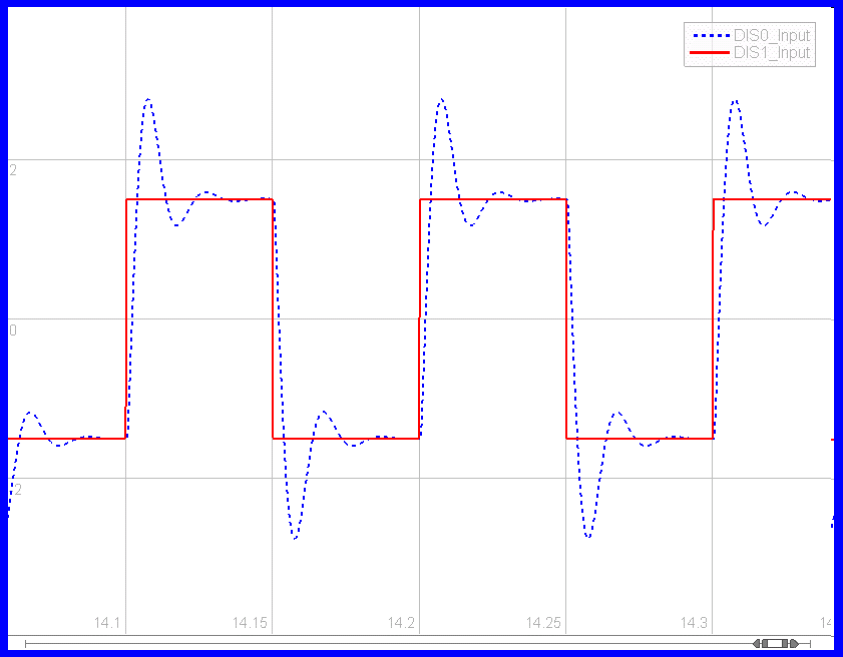
Linux Multi-processor platform
For real-time Simulation
(Virtual Test Bed - Real Time)

DSpace for Rapid Control
Prototyping

Real-Time Control



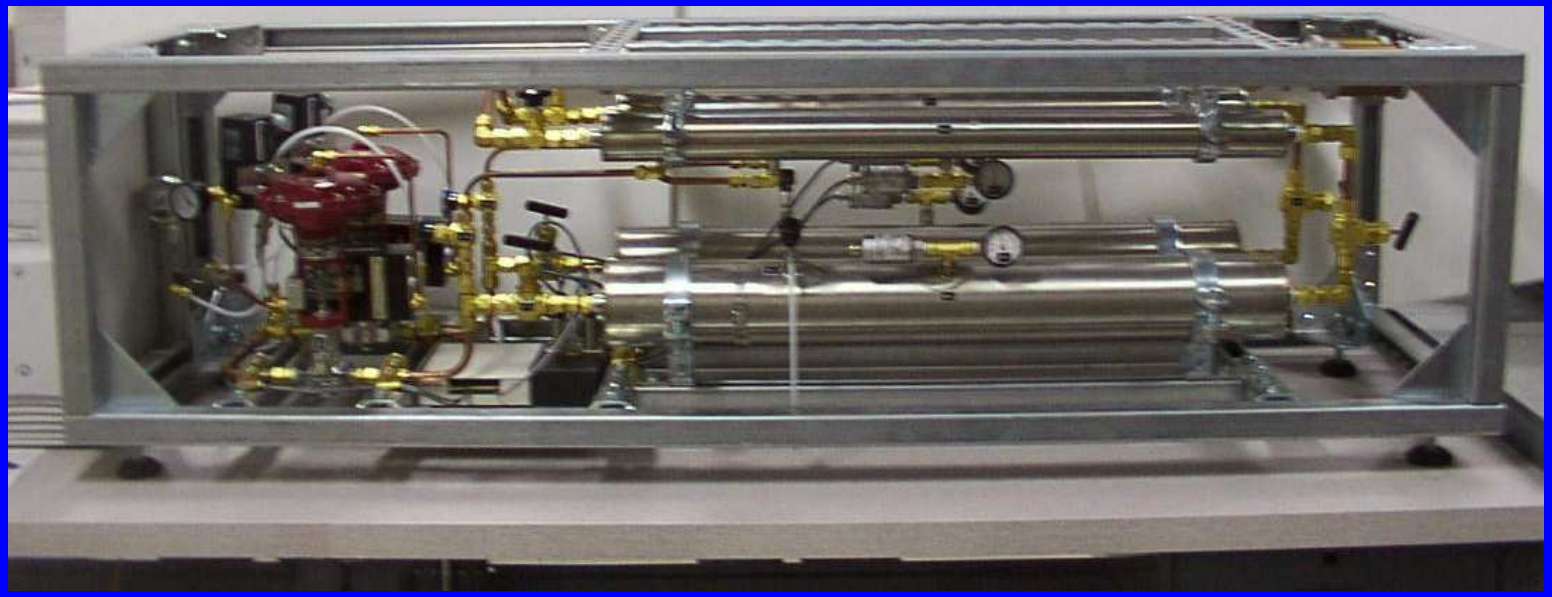
Open Loop Simulation
In Real-Time
(VTB Real-Time)



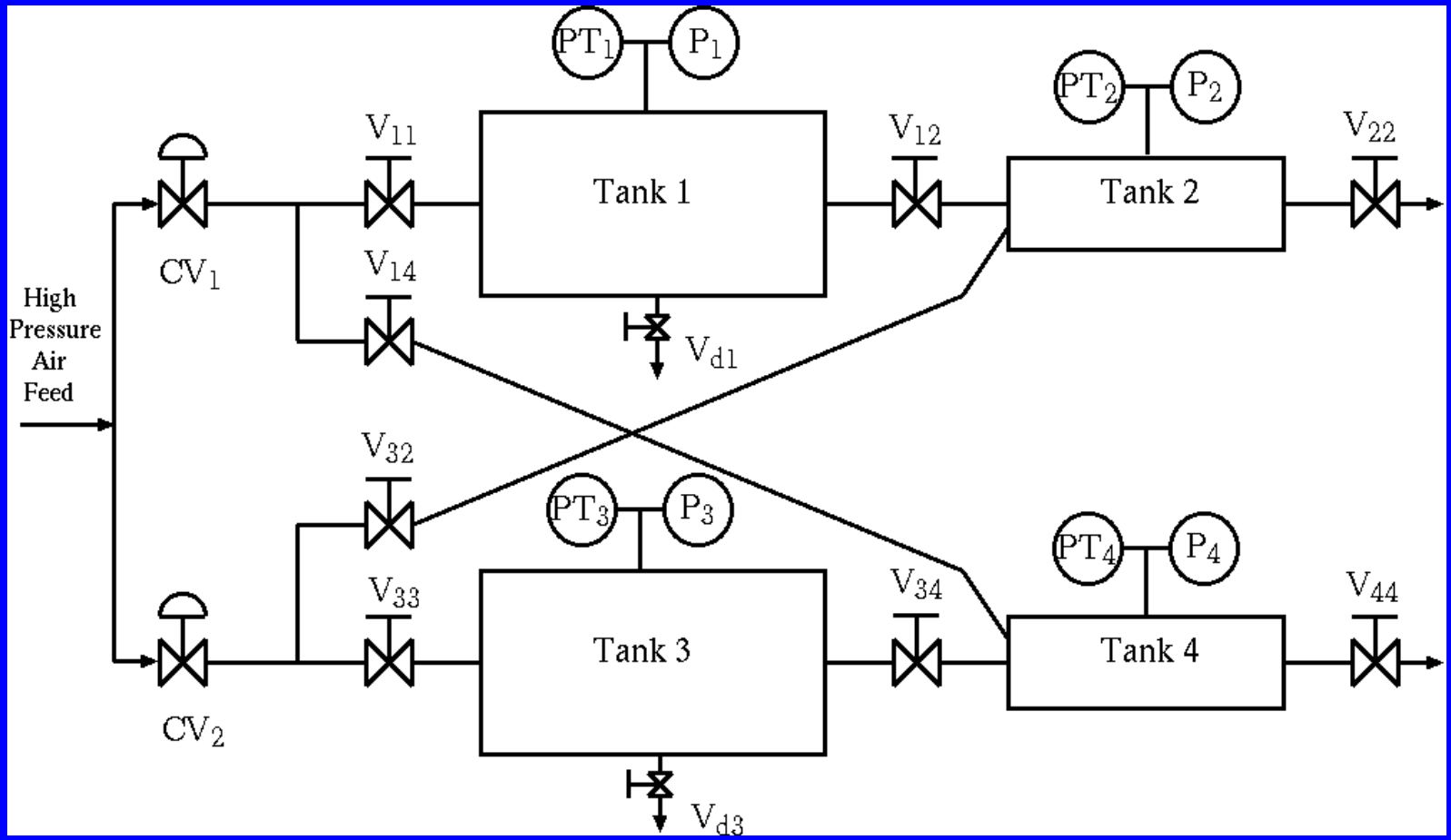
Open Loop Simulation
In Windows PC platform
(VTB)

Pressure Tank System

- Four air tank system running at < 50 psi
- Two control valves with positioners for actuation
- Four tanks with measured pressure

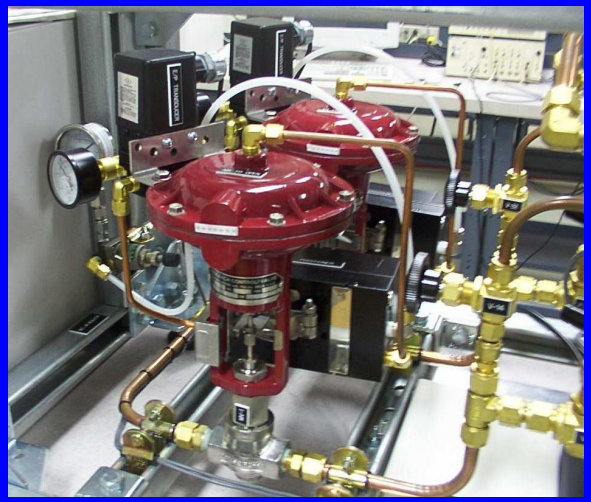


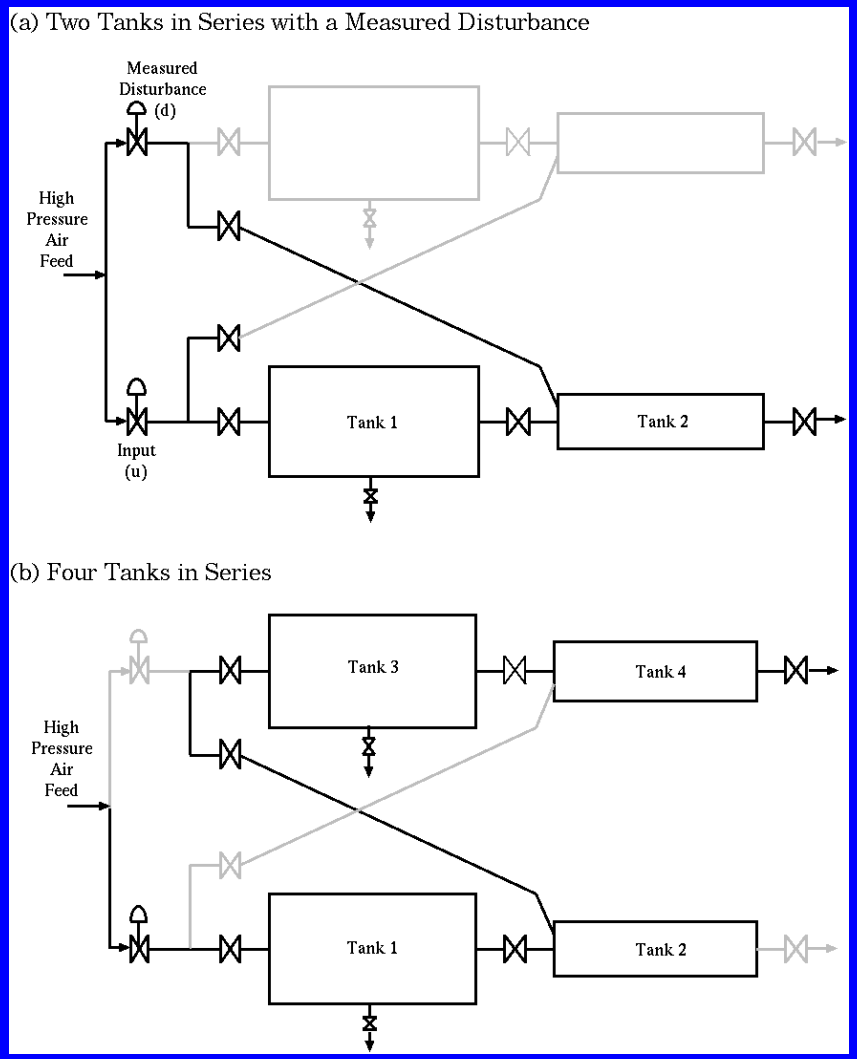
Pressure Tank Process Flow Diagram



Pressure Tank Configurations

- Various possible configurations
  - Feedforward
  - Tanks in series
  - Tanks in parallel



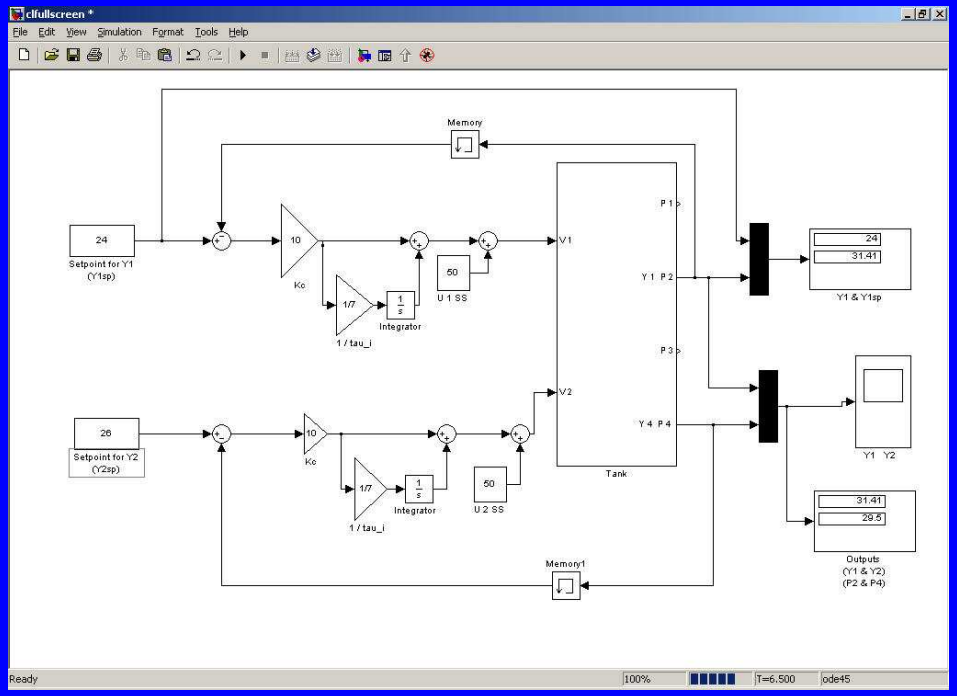


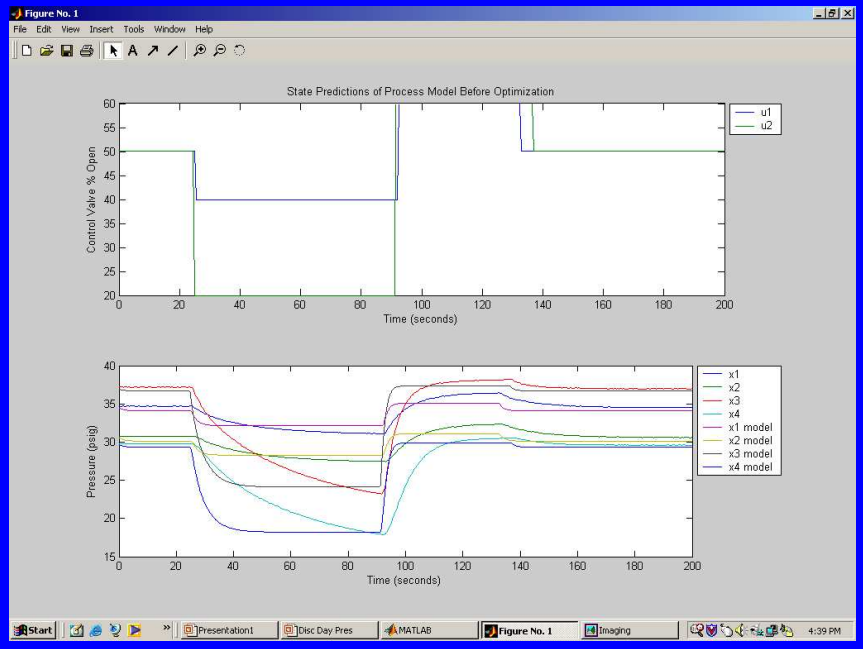
Pressure Tank System Topics

- Multivariable dynamic modeling
- System can exhibit multivariable RHP zero
- Subspace Identification
- Feedforward control
- Model Predictive Control (MPC)
- Nonlinear parameter estimation
- State Estimation

Pressure Tank System Computer Interface

- Matlab based quasi-real time interface
- IO toolbox interface to National Instruments DAQ





FRED – Filtration Research Experimental Design

- Developed with Savannah River Site for filtration studies
- Students tour facility to examine DCS system from Emerson and see real equipment
- Students work with Process and Instrumentation Diagrams (P&ID) to trace lines and find pieces of equipment

Anecdotal Student Feedback

"I like the 4 tank system. It helps me see that real world systems are very different from models of systems."

"The 4 pressure tank system is fast and flexible. We are able to demonstrate a number of different control strategies with it."

"Need more variety for lab experiments."

"Overall, course was interesting all semester long. Class worked well. It is somewhat graduate material."

"The course introduced some advanced topics in process control which I liked"

"The course can be even more restrictive to certain topics and be dealt with in greater depth."

"Better depth than 550. More hands-on experiments to better understand objectives."

Preliminary CHE Lego System

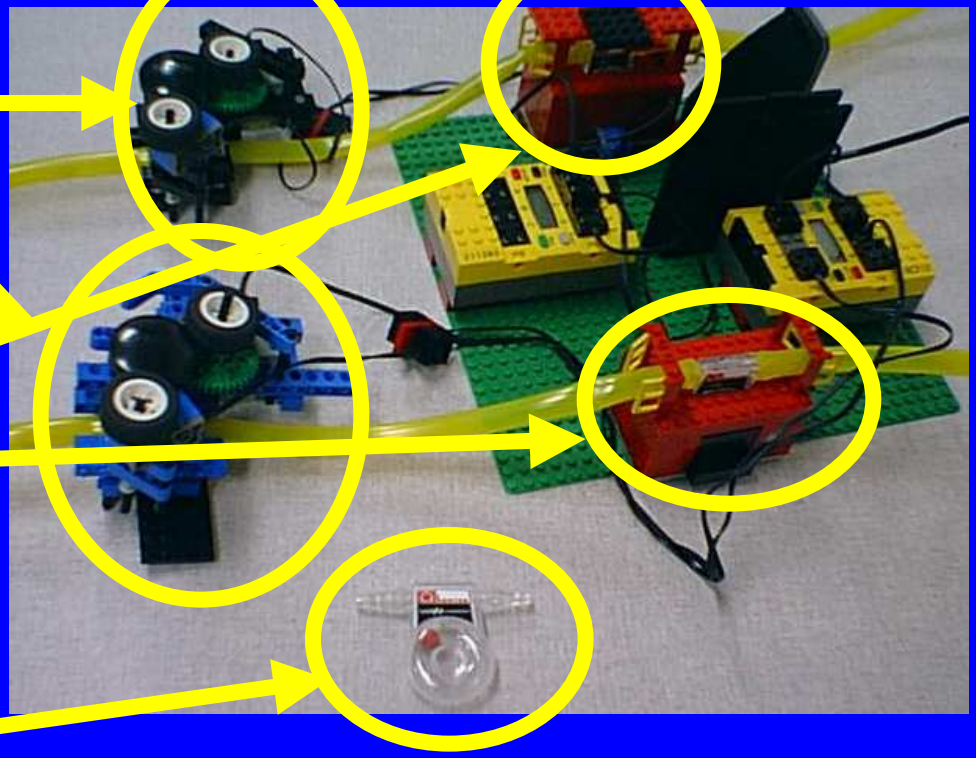
- Motivation:
  - First Lego League competitions
  - Student outreach
- Using Lego Mindstorm RCX, have developed
  - Control valves with local feedback positioner
  - Flow meters using light sensors and flow indicators
  - Concentration indication using bare wire
- Using multiple RCX bricks and NotQuiteC
- Goal, 2x2 mixing tank system.
  - Change two flows, control flow and temp. (or conc.)

Preliminary CHE Lego System

Swagelock Valves
with position sensor

Flow sensors

Flow Indicator



Problems With Course

- Need additional mechanical / electrical systems
- Need better mechanical / electrical students
  - Not quality problem (prerequisites)
- Time required for lab development
- Need to keep their attention while not being trivial
- Need labs that successfully demonstrate theoretical concepts
- Need robust experiments

Conclusions

- Described experiences with an advanced undergraduate industrial controls course
- Provided course outline with various topics
- Experiments for multi-disciplinary application
  - PLC programming, pendulum system
  - Real-time simulation, pressure tank system
- Preliminary work with Lego RCX for CHE

- Acknowledgements: NSF CTS-0238663