Twin-Screw Food Extruder: A Multivariable Case Study for a Process Control Course

- Process Control Course Overview
- Case Studies
  - Realistic Industrial Problems
  - Motivating to Students
  - Integrate Techniques Learned Throughout Course

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- Four credit hours, Spring Junior year
- Three 2-hour sessions/week
- Studio: Lectures and Simulations
- Major Case Study Project
  - Selected from multiple options
  - Teamwork
  - Written reports & frequent meetings
  - Final oral presentation
- Link between theory and practice
  - “Feels real”
  - Multivariable
  - Noise, constraints
Case Study Projects

- **Final 1/3 of Course**
- **Choice of Projects**
  - Reactive Ion Etcher
  - Lime Kiln
  - Fluidized Catalytic Cracking (FCCU)
  - Anaerobic Sludge Digester
  - Drug Infusion Control (Critical Care)
- **Different Advisor (Instructor/TA/RA) for Each Project**
- **Written Reports & Final Presentation**
Project Stages

- Literature review  Week 1
- Model development  Week 2
- Single input-single output (SISO) controller design  Week 3
- Multiple loop design  Week 4
- Oral presentation  Week 5
- Final written report  Week 5

Primary Goals:
Learn MIMO Modeling, Analysis and Control
Integrate basic concepts learned throughout the semester
Twin-Screw Cooking Food Extruder

- Common food processing unit, mostly in baking industry
- Fast-speed bioreactor with heating, cooling, compressing, mixing, evaporating, cutting, and aerating in one unit
- Twin-screw is now becoming more common, as it is easier to manipulate a number of parameters

www.foodprocessing-technology.com
Process Simulation (MATLAB/Simulink)

Case-Study Plant Model for the Twin-Screw Food Extruder

Subsystem of "Actual Plant" Unit Based on State-Space Model
Step Tests to Develop Model

Model vs. Extruder Comparison of Screw Speed Step Change

Output 1

Output 2

Input 1

Input 2
Step Tests to Develop Model

Noise and mismatch

Output 1

Output 2

Input 1

Input 2
SS-MT SISO Control

Effect of tuning parameter values
Relative Gain Analysis (RGA) for “Pairing”

Process Gain matrix =

\[
\begin{bmatrix}
  k_{11} & k_{12} \\
  k_{21} & k_{22}
\end{bmatrix} =
\begin{bmatrix}
  -.32 & -.87 \\
  .12 & -2.4
\end{bmatrix}
\]

\[
\Lambda =
\begin{bmatrix}
  \lambda_{11} & \lambda_{12} \\
  \lambda_{21} & \lambda_{22}
\end{bmatrix} =
\begin{bmatrix}
  \frac{k_{11}k_{22}}{k_{11}k_{22} - k_{12}k_{21}} & \frac{-k_{12}k_{21}}{k_{11}k_{22} - k_{12}k_{21}} \\
  \frac{-k_{12}k_{21}}{k_{11}k_{22} - k_{12}k_{21}} & \frac{k_{11}k_{22}}{k_{11}k_{22} - k_{12}k_{21}}
\end{bmatrix} =
\begin{bmatrix}
  .88 & .12 \\
  .12 & .88
\end{bmatrix}
\]

\(\lambda_{11}\) & \(\lambda_{22}\) are closer to one, and therefore are the better control loop pairings.

This means the two control loops are:

SS (screw speed) controlling MT (motor torque)

MC (moisture content) controlling PT (product temperature)
Best “Pairing” based on RGA
Simultaneous Setpoint Changes
Simultaneous Setpoint Changes
Disturbance Rejection
(change in barrel temperature)
RGA Validation: Opposite Pairing

Response of Improper RGA MVSISO in Strong SVD Direction

- Metal Temp (%)
- Product Temp (°C)
- Screw Speed (RPM)
- Moisture Content (%)

Time (sec)
Textbook

Chapters
1. Introduction
2. Fundamental Models
3. Dynamic Behavior
4. Empirical Models
5. Introduction to Feedback Control
6. PID Controller Tuning
7. Frequency-Response Analysis
8. Internal Model Control
9. The IMC-Based PID Procedure
10. Cascade and Feed-Forward Control
11. PID Enhancements
12. Ratio, Selective, and Split-Range Control
13. Control-Loop Interaction
14. Multivariable Control
15. Plantwide Control
16. Model Predictive Control
17. Summary

Modules
1. Introduction to MATLAB
2. Introduction to Simulink
3. Ordinary Differential Equations
4. MATLAB LTI Models
5. Isothermal Chemical Reactor
6. First-Order + Time-Delay Processes
7. Biochemical Reactors
8. Continuously Stirred Tank Reactor (CSTR)
9. Steam Drum Level
10. Surge Vessel Level
11. Batch Reactor
12. Biomedical Systems
13. Distillation Control
14. Case Study Problems
15. Flow Control
16. Digital Control
Summary

- **Laptop Studio-based Course**
  - Lectures followed by simulation-based reinforcement of theory

- **Case Study Projects**
  - Choice of 5 projects, final 1/3 of course
  - Integrates concepts learned throughout course
  - Multivariable focus
  - Twin screw food extruder