Objectives of the Class

- Application of process control techniques
- Advanced process control
  - Feedforward control, ratio control, override control
  - Selective control, optimizing control, valve position control
  - Etc.
- Multivariable process
  - Interaction analysis
  - Multiloop PID control
- Model Predictive Control
- Supervisory and statistical control
- Java applets will be used to understand the concepts better
- Matlab

SYLLABUS

- Based on the basic process control concepts, advanced control techniques such as feedforward control, ratio control, cascade control, multiloop control, model predictive control, statistical control and etc. will be taught and practiced.

- Lecture hour
  - 15:30-16:45 Monday, (Eng. Bldg. 162)
  - 15:00-16:45 Wednesday, (Eng. Bldg. 162)

- Textbook
  - Lecture note
    (http://www.cheric.org/education/lecture/process/CHBE495)

- Lecture aids
  - Java Applets
  - Matlab

- Course Grading
  - Attendance(10%)
  - Participation (10%)
  - Project(30%)
  - Final exam(30%)
  - Homework(20%)

- Office hour
  - Basically, anytime when I am available. If you need appointment, call 3298
  - Also, you can get some assistance from graduate students of the process systems laboratory (Eng. Bldg II #233)
PROLOGUE

• How to use Matlab
  - You need license.
  - Recommend student version.
  - Basics of Matlab language
  - Simulink
  - Toolboxes

FEEDFORWARD CONTROL

• Feedback control
  - Corrective action based on process output (CV)
  - If PID is used, no \textit{a priori} knowledge is required
  - However, it can respond only after some changes occurs in CV

• Feedforward control
  - Based on the measurement of disturbance, feedforward controller can respond even before any changes occurs in CV
  - It requires process model which can predict the effect of disturbance on CV
  - If there are some modeling error, feedforward control action will be erroneous (No corrective action)

• Typical example
  - Boiler level control

• In order to overcome the shortcomings of the feedback or feedforward controls, combine them!
  ➔ Feedforward-feedback control
**Tank heater control**
- Tank level control (feedback)
- Outlet temp. control (feedforward-feedback)

If cold water flow changes, feedforward controller will adjust the steam flow rate as soon as the cold water flow change is detected.

If the feedforward action is not enough due to the model error, measurement error and etc., feedback controller will compensate the difference.

**Static FF controller**
- The feed temperature must be measured.
- The desired exit temperature ($T_{sp}$) should be entered manually instead of the exit temperature.
- The feed flow rate should be measured or at least known.

$$P_f = \frac{wC}{U_w} (T_p - T_e) + \frac{1}{b} (T_p - \alpha) = \frac{1}{b} T_p + \frac{C}{U_w} wT_p - \frac{C}{U_w} wT_e - \frac{a}{b}$$

This FF controller is bilinear.
- If the model is accurate, a change in disturbance variables such as feed temperature, feed flow rate will be compensated eventually.
- The transient cannot be compensated with static FF control.

**DYNAMIC MODEL FOR CSTH (ENERGY BALANCE)**

$$mC \frac{dT}{dt} = wC(T_i - T) + U(a + bP_f - T)$$

Where \( T_i = a + bP_f \)

**Steady-state model for CSTH**

$$0 = wC(T_i - \bar{T}) + U(a + b\bar{P_f} - \bar{T})$$

$$\bar{P_f} = \frac{\bar{U}}{b} (\bar{T} - \bar{T}) + \frac{1}{b} (\bar{T} - \alpha)$$

Based on the steady-state relation between variables, a control law can be derived.

**Field applicable FF Controller**
- Transmitters
  - IP transducer and control valve
- FF control law

$$M' = p = K_i (\bar{T} - T_i) + K_i w \bar{T}_w - K_i w \bar{T}_m - K_i w - K_i \bar{T}_m - K_i$$

where

- $$K_i = \frac{1}{bU_kK_p}$$
- $$K_i = \frac{K_i}{bU_kK_k}$$
- $$K_i = \frac{K_i}{bK_p}$$
- $$K_i = K_i (K_k - \alpha)$$
- $$K_i = K_i (K_k - \alpha)$$
- $$K_i = K_i (K_k - \alpha)$$
Dynamic Feedforward Controller Design

- **Closed-Loop Transfer Function for Load Change**
  
  \[ C(s) = \frac{G_L + G_D G_F G_p}{1 + G_D G_F G_p} \]

  - Ideal FF control: \( C(s) = 0 \)
  - Dynamic feedforward controller

  \[ G_L + G_D G_F G_p = 0 \Rightarrow G_f = \frac{-G_L}{G_D G_F G_p} \]

  - Theoretically, perfect disturbance rejection is possible.
  - FF controller can be quite complex
  - The stability is not affected by FF controller

- **Examples**
  1) \( G_f = \frac{K_f}{\tau_p s + 1} \quad G_f = \frac{K_f}{\tau_p s + 1} \Rightarrow G_f = \frac{-K_p}{K_D K_F \tau_p s + 1} \) (Lead-lag type)
  2) \( G_f = \frac{K_f}{\tau_p s + 1} \quad G_f = \frac{K_f e^{\tau_p s}}{\tau_p s + 1} \Rightarrow G_f = \frac{-K_p}{K_D K_F \tau_p s + 1} \) (Time lead: physically unrealizable)
  3) \( G_f = \frac{K_f}{\tau_p s + 1} \quad G_f = \frac{K_f}{(\tau_p s + 1)(\tau_p s + 1)} \Rightarrow G_f = \frac{-K_p}{K_D K_F \tau_p s + 1} \) (Not proper: physically unrealizable)

  ➤ Remedy: Use a lead-lag type FF controller and tune it.

- **Comparison of static and dynamic FF Controller**

- **Example**

\[ T(s) = \frac{K_p}{\tau_p s + 1} P(s) + \frac{K_{1L}}{\tau_{L1} s + 1} W(s) + \frac{K_{1H}}{\tau_{L2} s + 1} T(s) \]
Tuning Feedforward Controllers

- **Feedforward controller gain** ($K_f$)
  - Calculate from the model and adjust so that the offset can be eliminated for some change in load

- **Lead and lag time constants**
  - Lead: add all the time constants in the numerator plus time lead of the ideal FF controller
  - Lag: add all the time constants in the denominator of the ideal FF controller
  - Fine tuning:
    - From initial guesses of the time constants,
    - Adjust lead so that the areas of above and below the set points in the response of step change in disturbance are about same.
    - Then adjust the lag until satisfaction while the difference between lead and lag is maintained constant.

**Example**
- Increase lead: speed up to the steady state
- Decrease lead: slow down to the steady state

**Configurations for Feedforward-Feedback Control**

- Feedback trim
- FF does not affect the stability
- Another way is that the FB controller output adjust the FF controller gain

**A Typical Block diagram for FF-FB control**

Figure 17.11. A block diagram of a feedforward-feedback control system.
Ratio Control

- A special type of FF control
- Objective: maintain the ratio of two variables

\[ R_e = \frac{M}{L} \]

- \( M \): Manipulated variable
- \( L \): Load variable
- The calculation of ratio is performed in terms of the original variables, rather than deviation variables
- Typical applications
  - Blending operations
  - Maintaining a stoichiometric ratio of reactants to a reactor
  - Keeping a specified reflux ratio for a distillation column
  - Holding the fuel-air ratio to a furnace at the optimum value

Ratio Control Schemes

- Method I
  - Constant process gain
  - Widely used (preferred)

- Method II
  - Actual ratio is calculated
  - Set point is desired ratio
  - Process gain varies (nonlinear)

\[ K_p = \frac{\frac{\partial R_e}{\partial M}}{\frac{\partial R_e}{\partial L}} = \frac{1}{L} \]