Control systems

Spring 2019 – Lecture #13

Reading: RWI Ch. 1 page 4 – 14 and Ch. 9, page 303 - 339
Open-loop control

**Possible Functions:**
- Threshold (limit trip)
- Amplification
- Inversion
- Filtering
- Time Delay

*Figure 1-3. Open-loop control*
Closed-loop control

Figure 1-6. Closed-loop control

Figure 1-7. Closed-loop fluid level control
Automated test setup

*Figure 1-9. Test instrumentation example*
Process control
Linear control systems

Equation 9-2.

\[ u(t) = K_p e(t) + P \]

Figure 9-1. Linear control system proportional response
Nonlinear control systems

*Figure 9-2. Nonlinear control system response*

*Figure 9-3. Nonlinear pulse control*
Sequential control systems

Figure 9-4. Sprinkler system sequential control

Sequential power control

Figure 1-8. Sequential power control
Control systems block diagram

Open-Loop Control System

\[ u = g(r) \]

Closed-Loop Control System

\[ u = g_1(e) \]
\[ c = g_2(u) \]
\[ b = h(c) \]

Figure 9-5. Control system block diagrams
Linear Time invariant (LTI) vs. Time variant systems

- LTI example: amplifier
- Time variant system example: aircraft autopilot
Discrete-time closed loop system

Figure 9-7. Discrete-time closed-loop control system
Control software flow / timing

Figure 9-8. Control system software flow

Figure 9-9. Control system software timing
Closed-loop water tank control system

Figure 9-11. Closed-loop water tank control system details

Figure 9-12. Water tank control system response graphs
Simple open-loop motor control

- Motor rotation rate will vary with load

\[ S_{\text{rpm}} = M \cdot G \cdot V_{\text{in}} \]

*Figure 9-13. Simple open-loop DC motor control*
Closed-loop motor velocity controller

Figure 9-14. Feed-forward DC motor velocity controller
PWM motor speed control

Figure 9-16. PWM motor speed control
Commercial DC motor controller

Figure 9-17. Commercial DC motor controller
Nonlinear bang-bang controllers

- On/off controller that switches between two states; either completely on or completely off.
- Often hysteresis is used!
PID controller

• Proportional-Integral-Derivative (PID) algorithm is the most common control algorithm
  – Used for heating and cooling systems, fluid level monitoring, flow control, and pressure control.
• Calculates a term proportional to the error - the P term.
• Calculates a term proportional to the integral of the error - the I term.
• Calculates a term proportional to the derivative of the error - the D term.
• The three terms - the P, I and D terms, are added together to produce a control signal that is applied to the system being controlled.
• Sometimes only a PI controller is used.
PID controller II

- A PID controller continuously calculates an error value as the difference between a measured process variable and a desired setpoint.
- The controller attempts to minimize the error over time, by adjustment of a control variable $u(t)$, such as the position of a control valve.

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{de(t)}{dt}$$

- $P$ accounts for present values of the error.
- $I$ accounts for past values of the error, accumulates over time.
- $D$ accounts for possible future values of the error, based on its current rate of change.
- Must tune the coefficients $K_p$, $K_i$ og $K_d$

In general PID does not provide optimal control, since no modelling of the Plant/process is used

Figure from wikipedia
Figure 9-24. PID control block diagram
PID controller tuning examples

overshoot

undershoot

= set point
Optimal control

- Estimation and control is related!
- The Kalman filter is typically used to provide optimal estimates of state variables that are implemented in a control algorithm.

Figure from Gelb