UiO : University of Oslo

FYS3240- 4240
Data acquisition & control

Control systems

Spring 2019– Lecture #13

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

Bekkeng 28.12.2018

Open-loop control

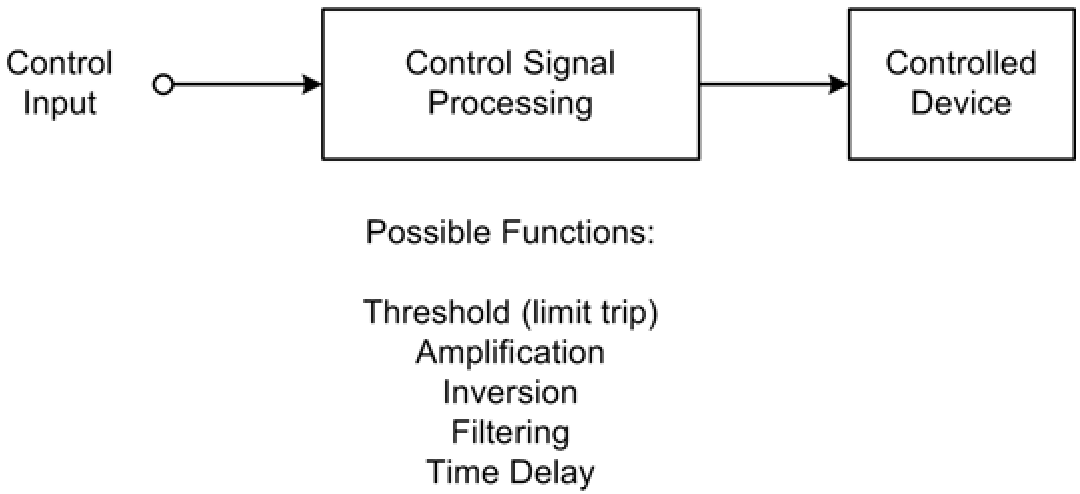
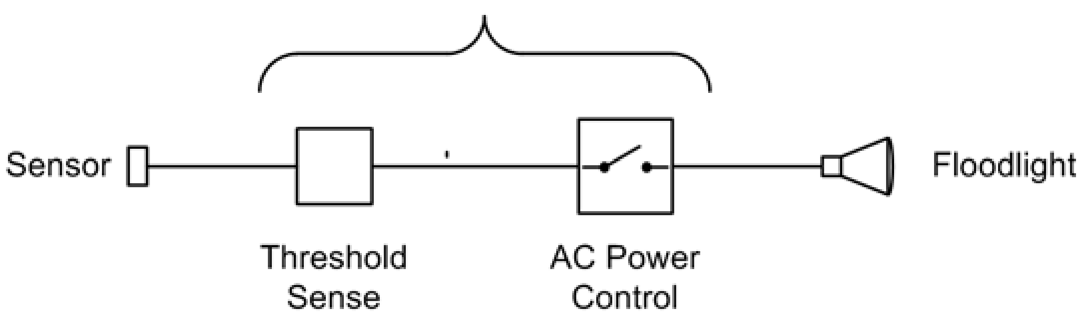
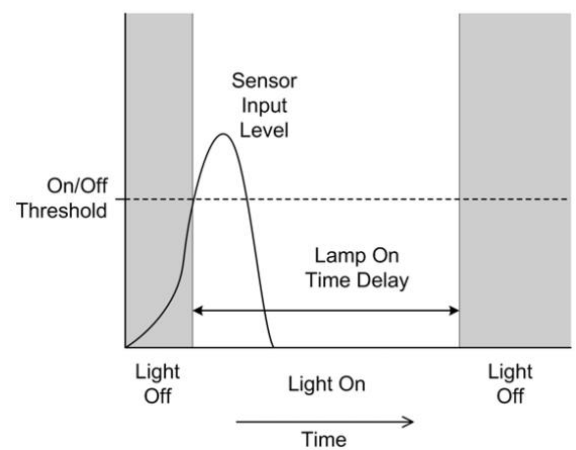


Figure 1-3. Open-loop control





Closed-loop control

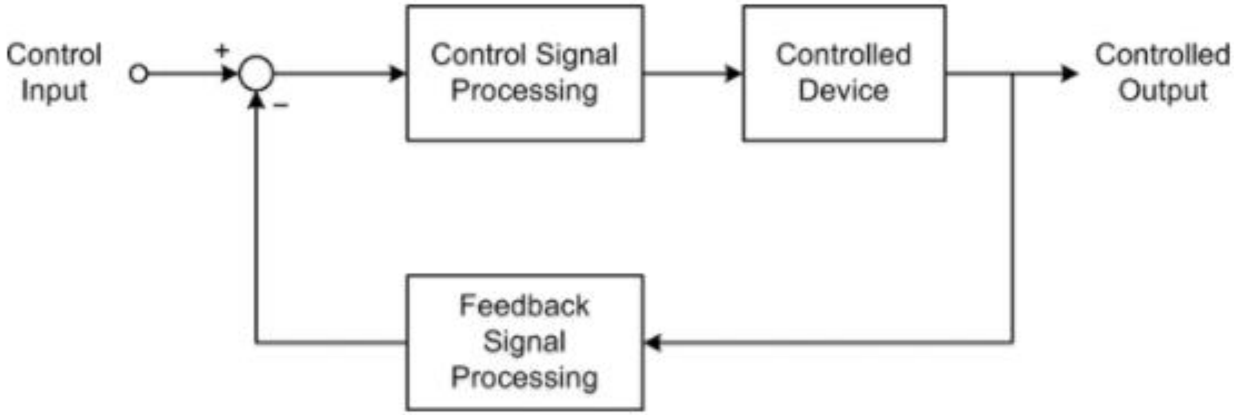


Figure 1-6. Closed-loop control

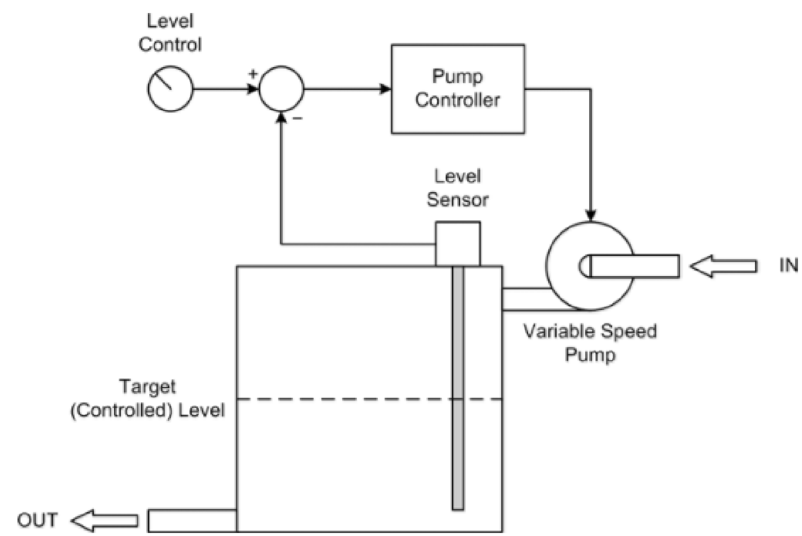


Figure 1-7. Closed-loop fluid level control

Automated test setup

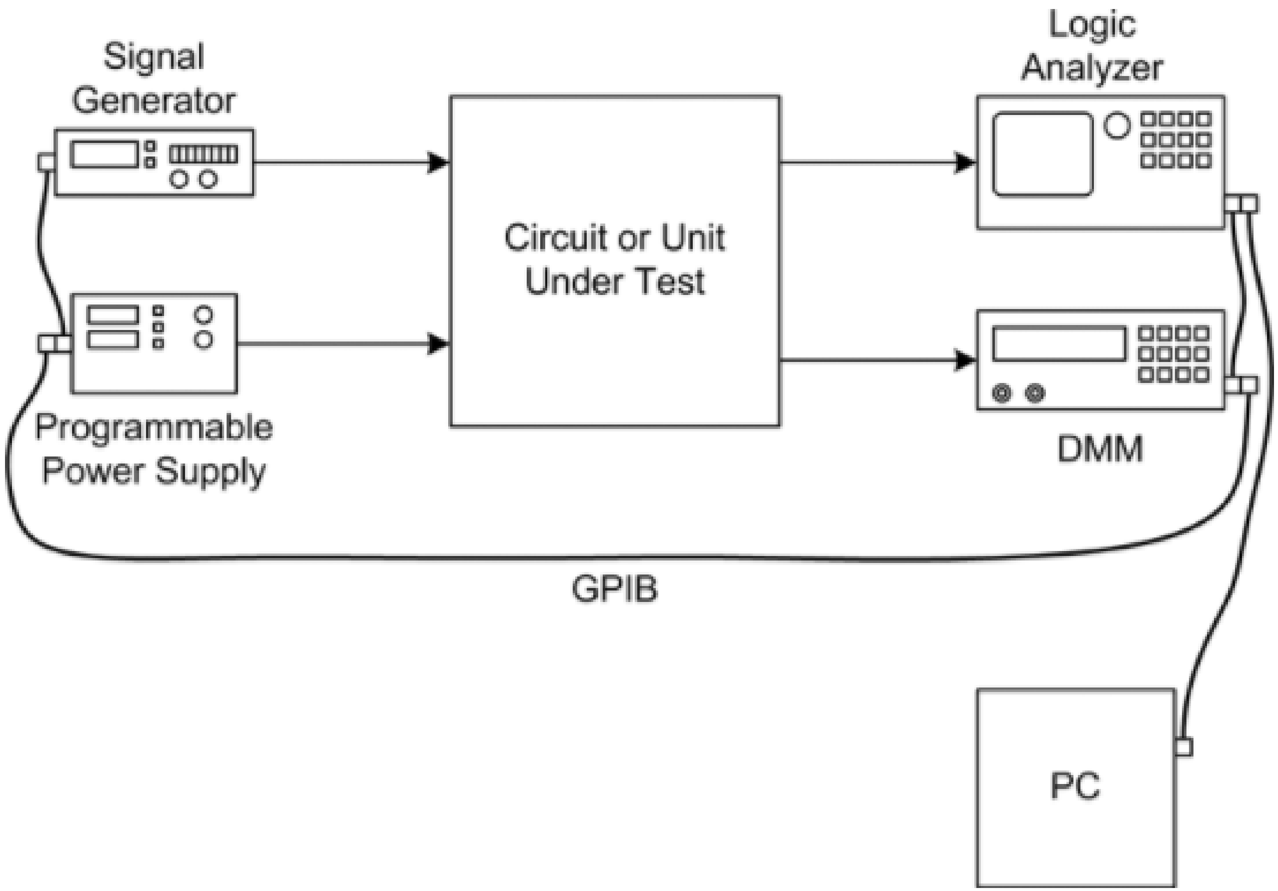
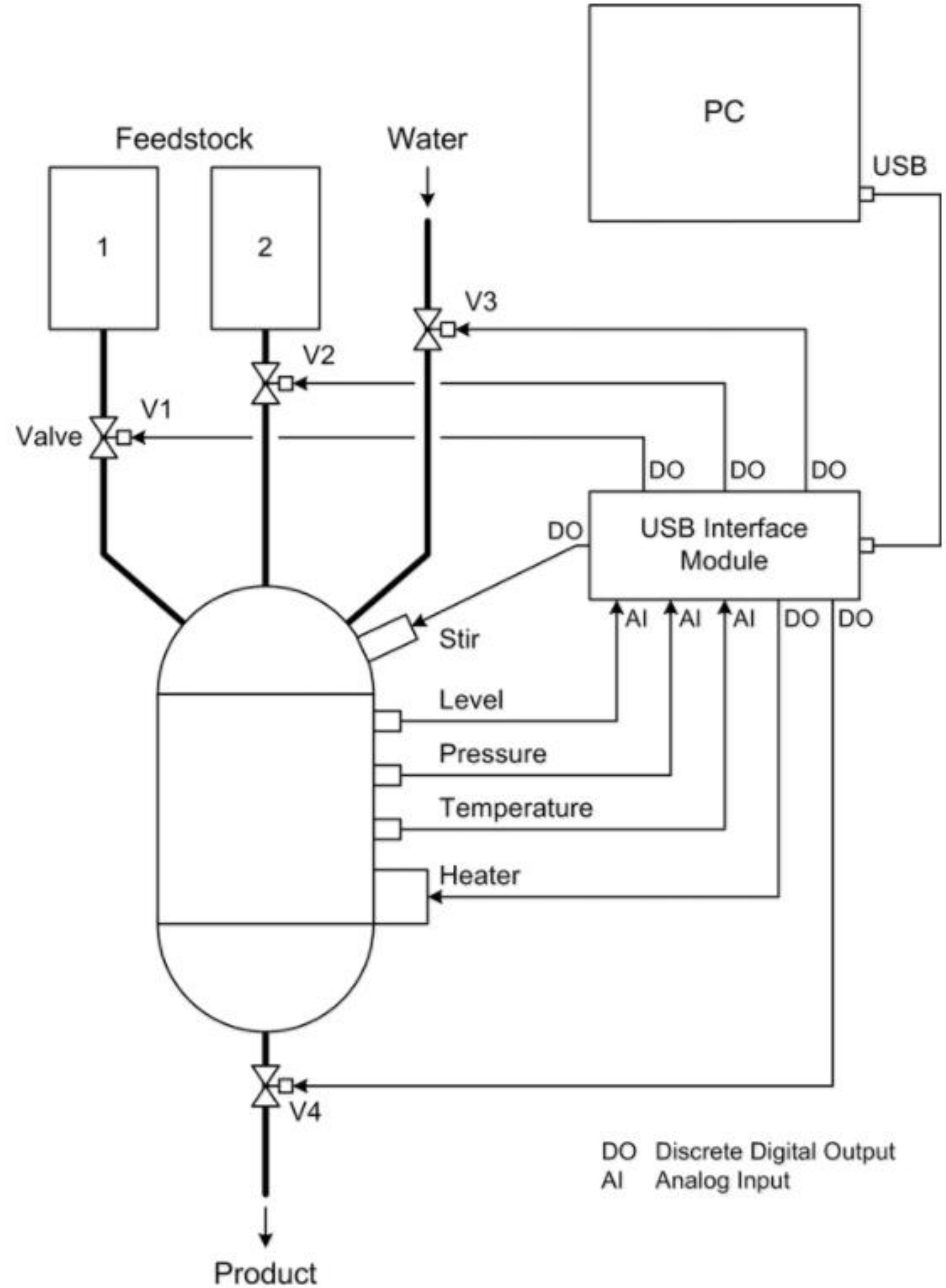


Figure 1-9. Test instrumentation example

Process control



Linear control systems

Equation 9-2.

$$u(t) = K_p e(t) + P$$

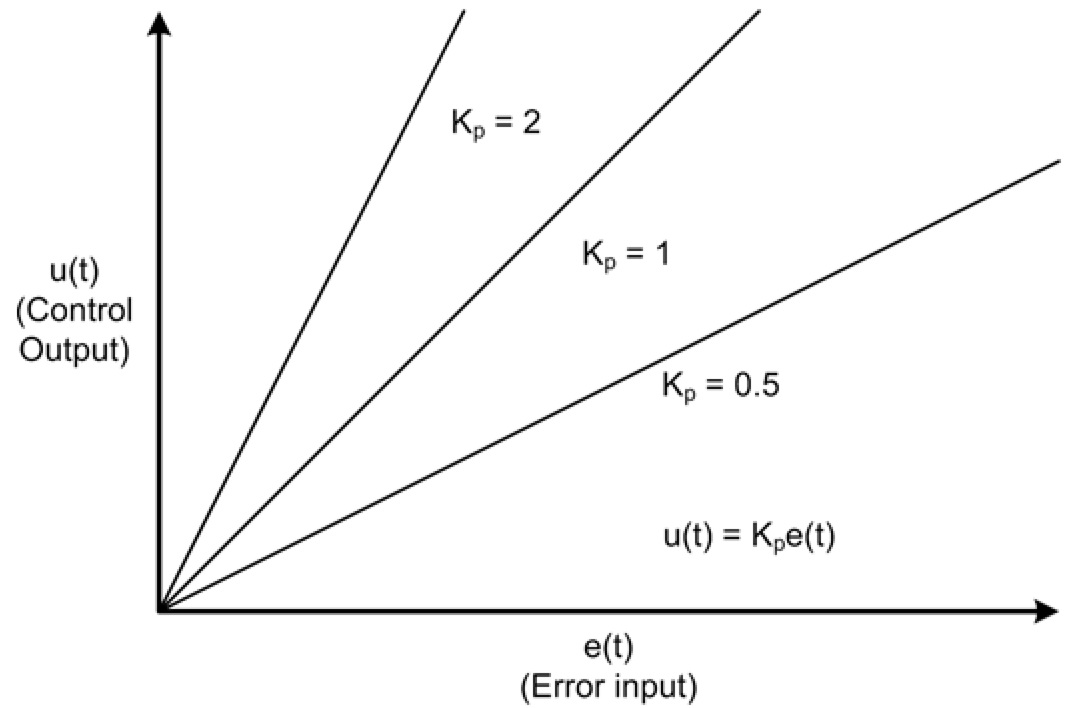


Figure 9-1. Linear control system proportional response

Nonlinear control systems

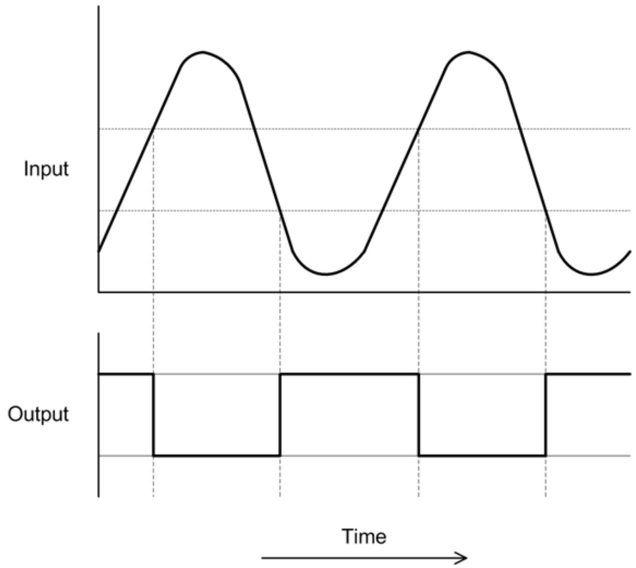


Figure 9-2. Nonlinear control system response

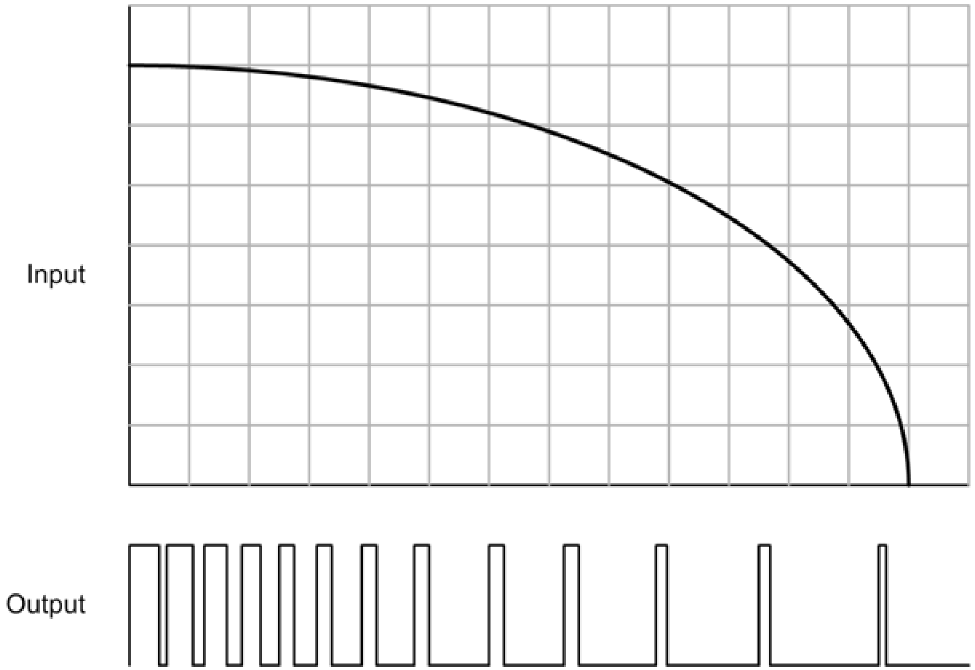


Figure 9-3. Nonlinear pulse control

Sequential control systems

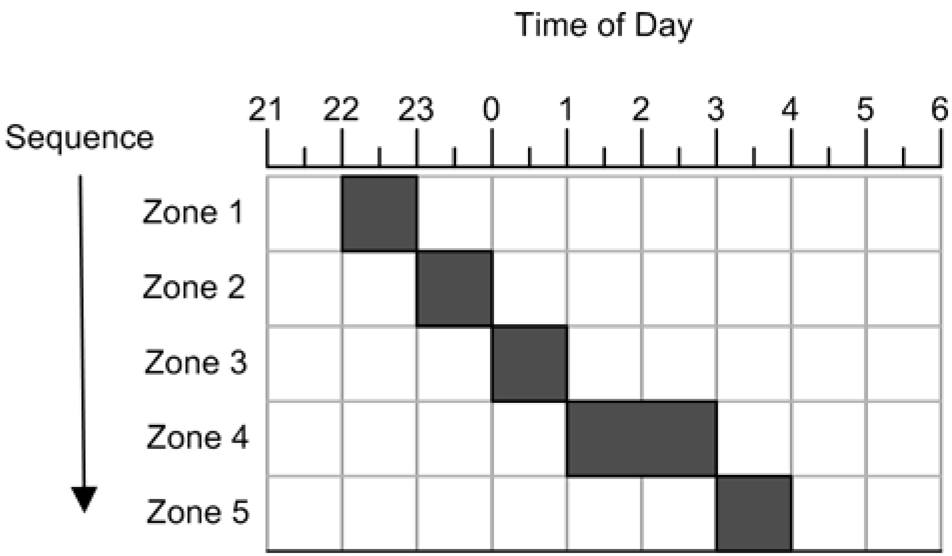


Figure 9-4. Sprinkler system sequential control

Sequential power control

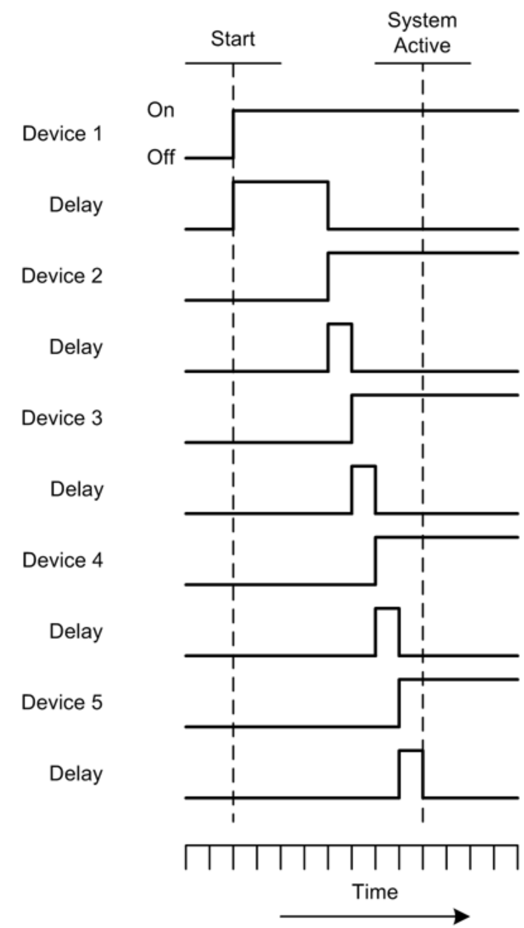


Figure 1-8. Sequential power control

Control systems block diagram

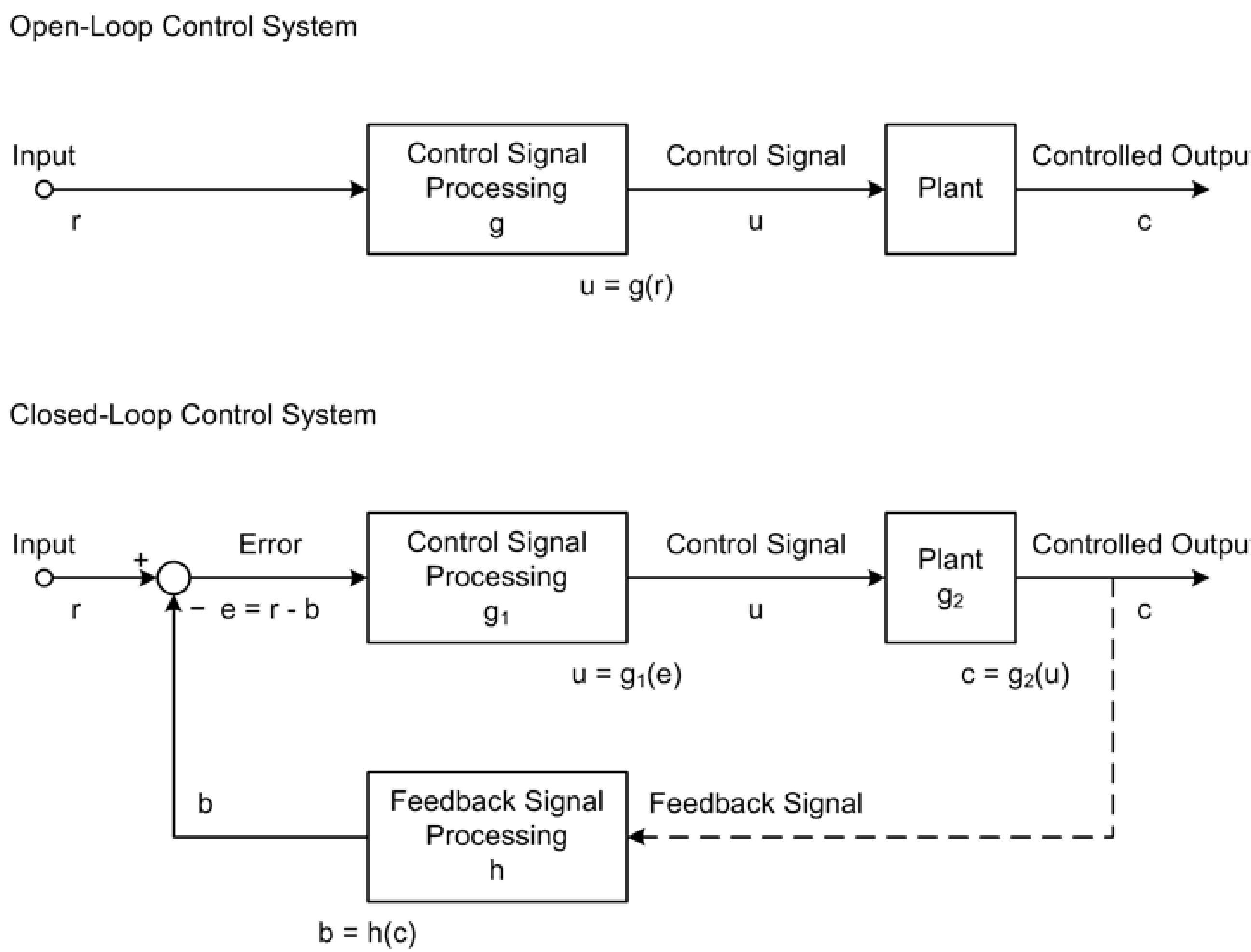


Figure 9-5. Control system block diagrams

Linear Time invariant (LTI) vs. Time variant systems

- LTI example: **amplifier**
- Time variant system example: **aircraft autopilot**

Discrete-time closed loop system

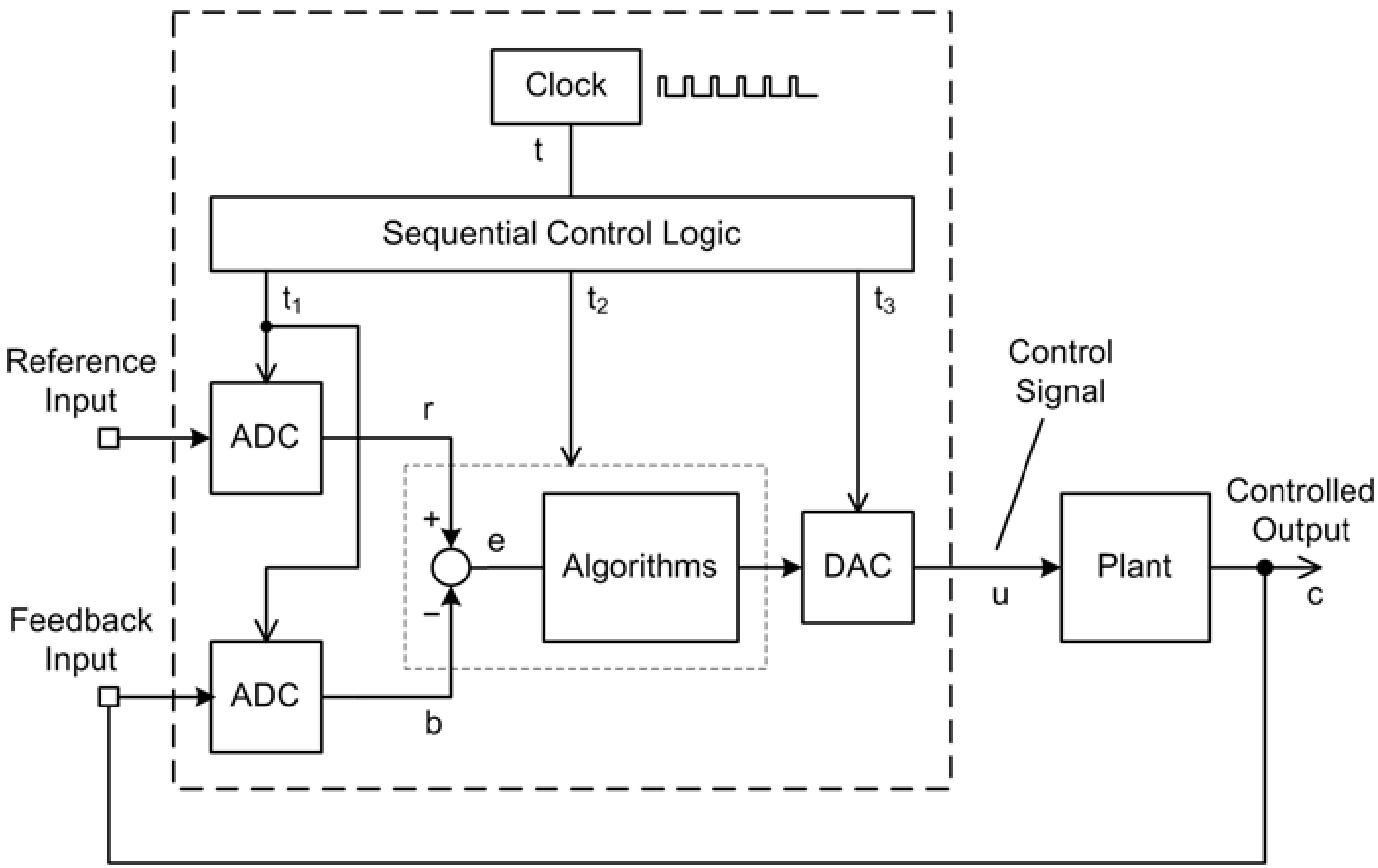


Figure 9-7. Discrete-time closed-loop control system

Control software flow / timing

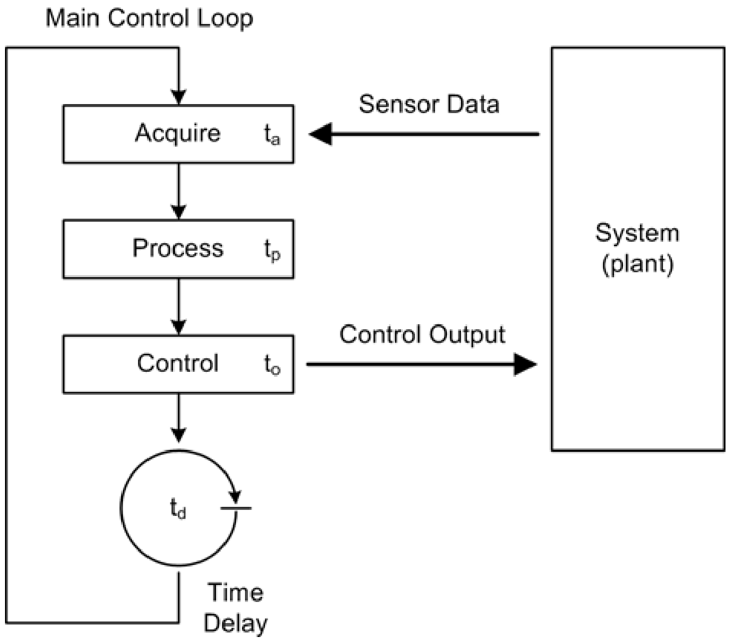


Figure 9-8. Control system software flow

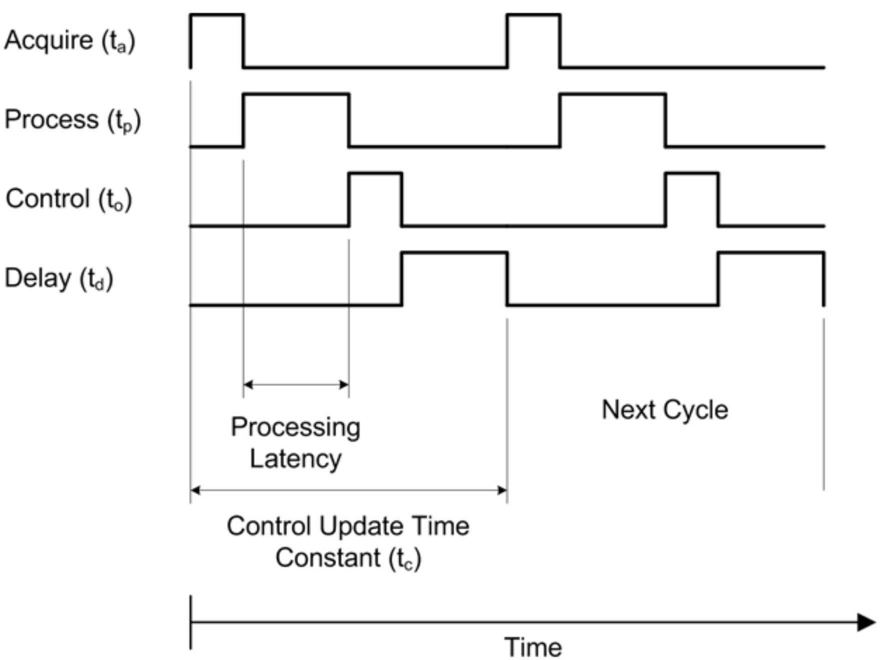


Figure 9-9. Control system software timing

Closed-loop water tank control system

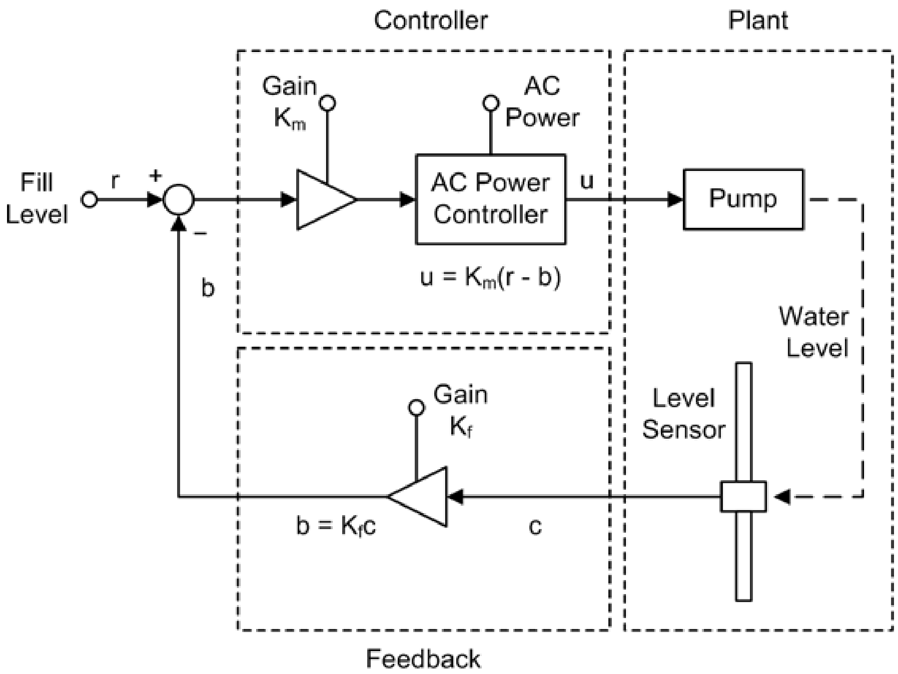


Figure 9-11. Closed-loop water tank control system details

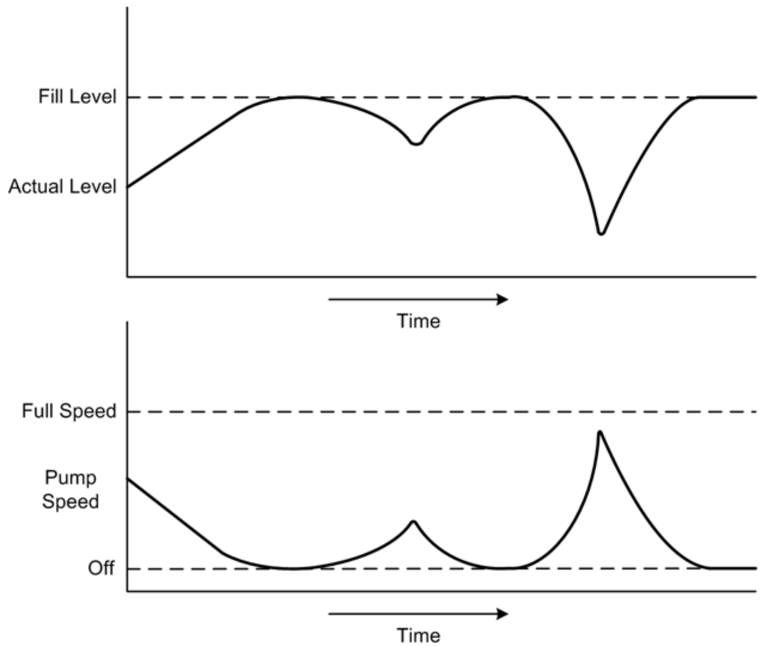


Figure 9-12. Water tank control system response graphs

Simple open-loop motor control

- Motor rotation rate will vary with load

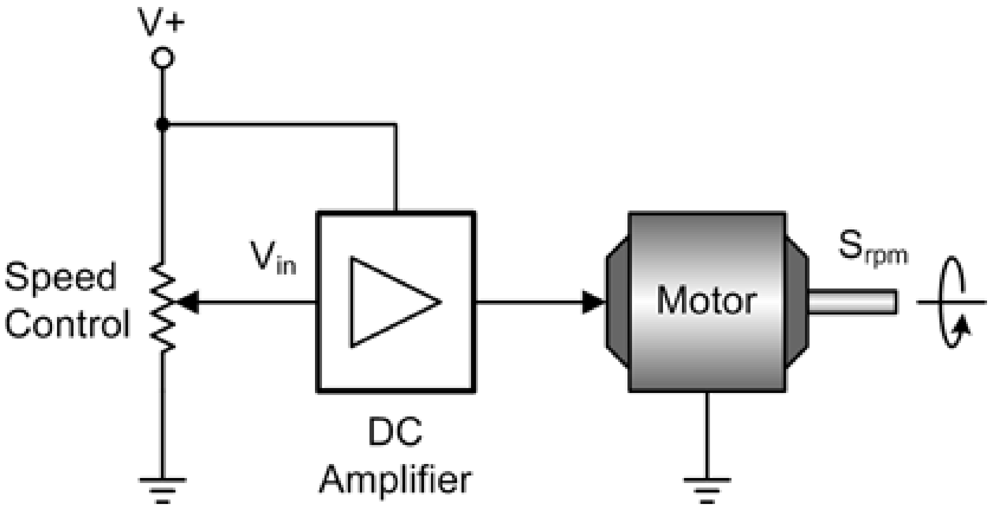


Figure 9-13. Simple open-loop DC motor control

$$S_{\text{rpm}} = M_r G V_{\text{in}}$$

Closed-loop motor velocity controller

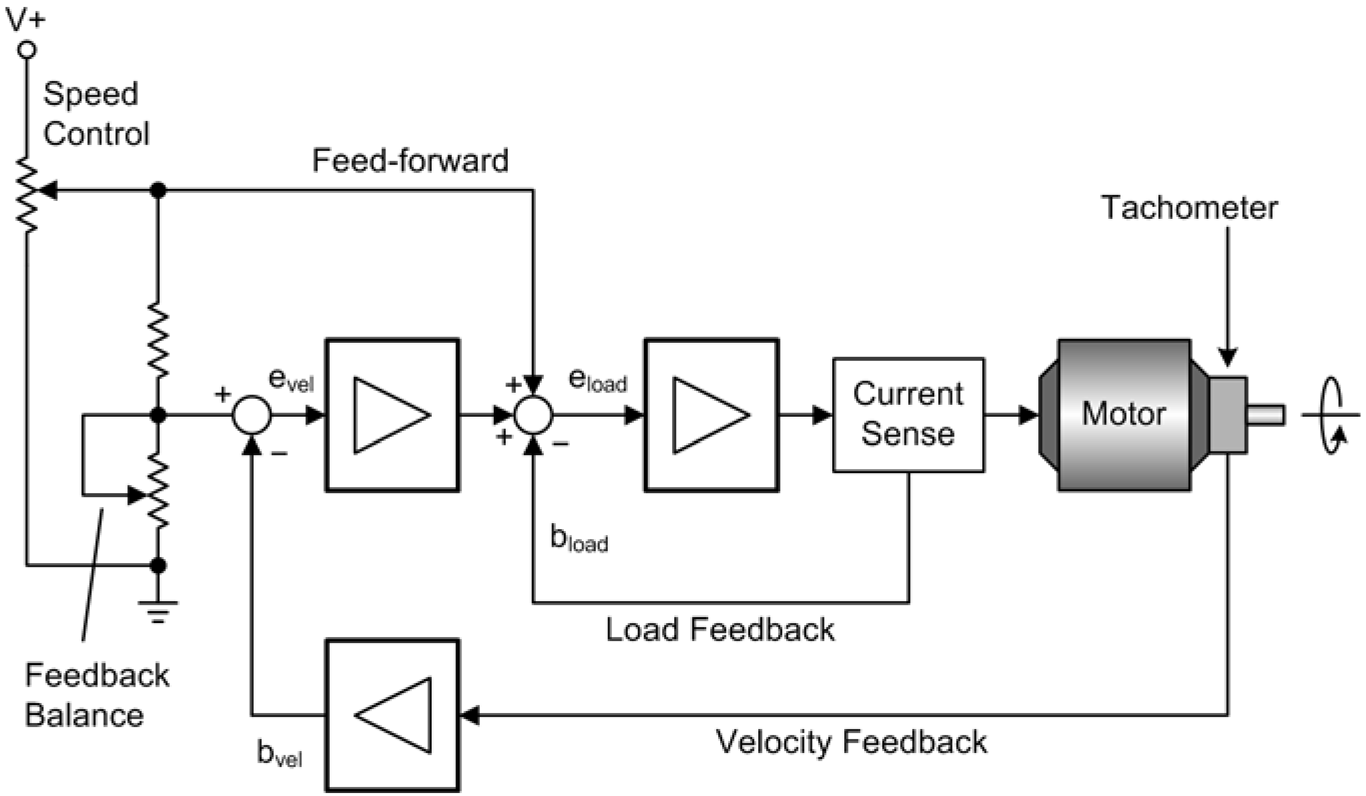


Figure 9-14. Feed-forward DC motor velocity controller

PWM motor speed control

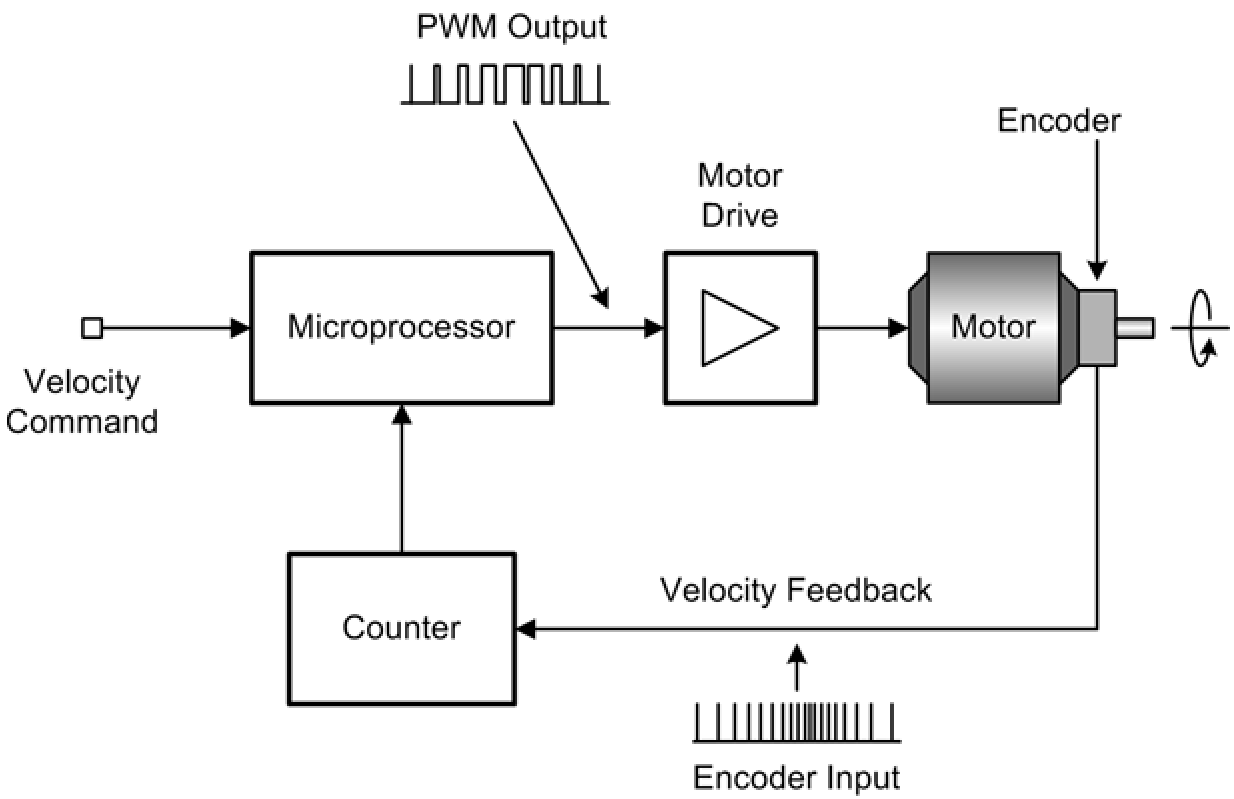


Figure 9-16. PWM motor speed control

Commercial DC motor controller

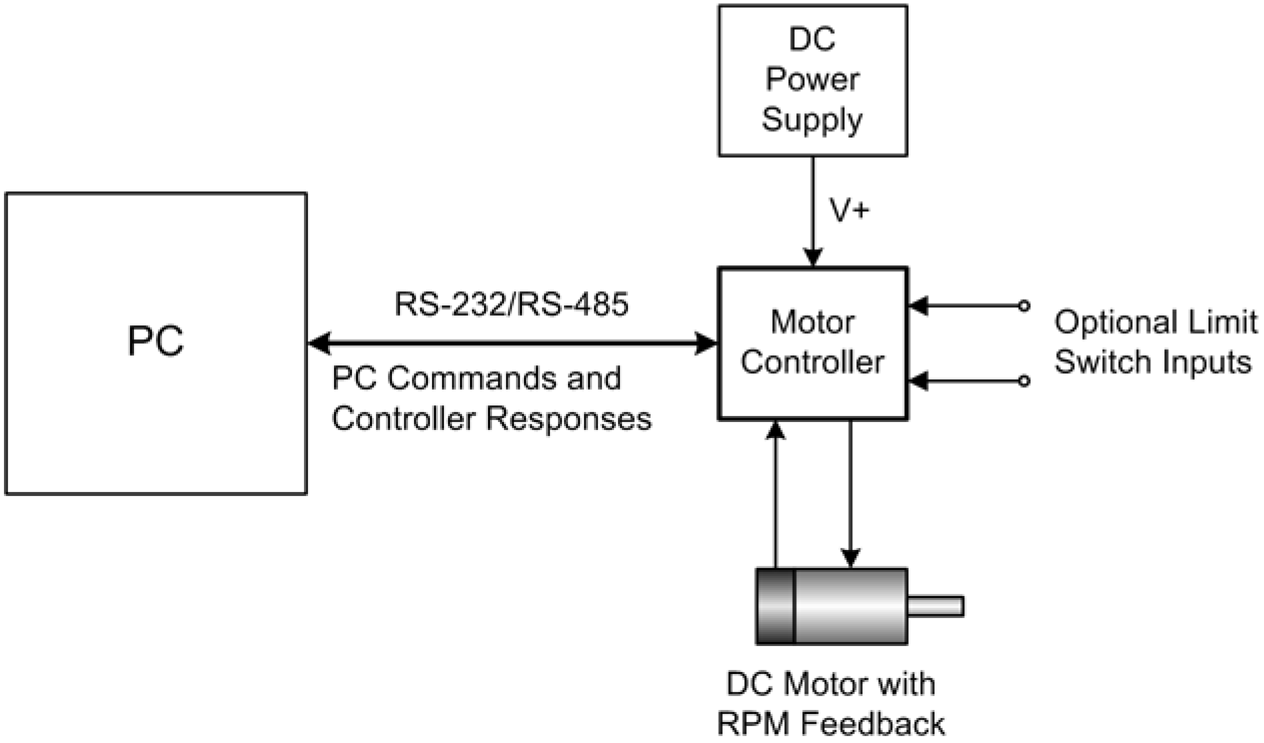


Figure 9-17. Commercial DC motor controller

Nonlinear bang-bang controllers

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

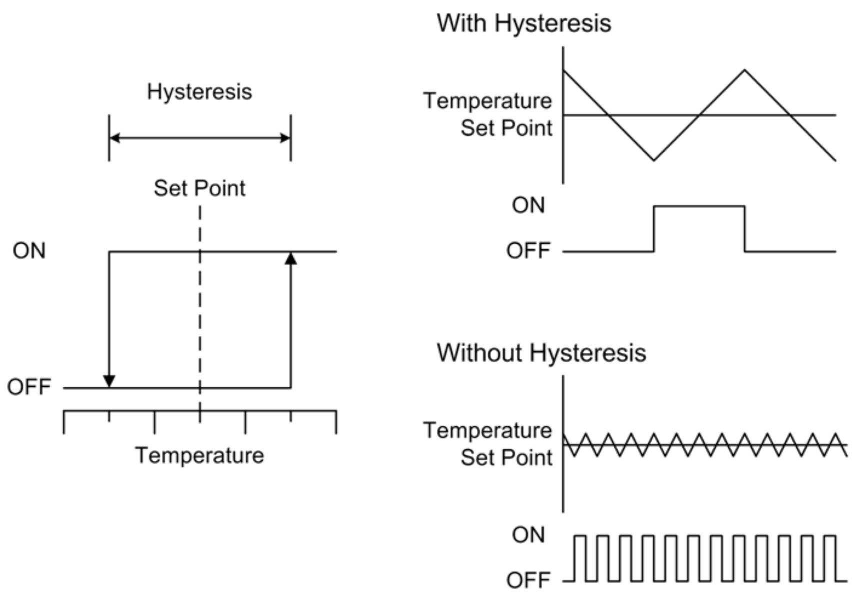


Figure 9-18. Hysteresis

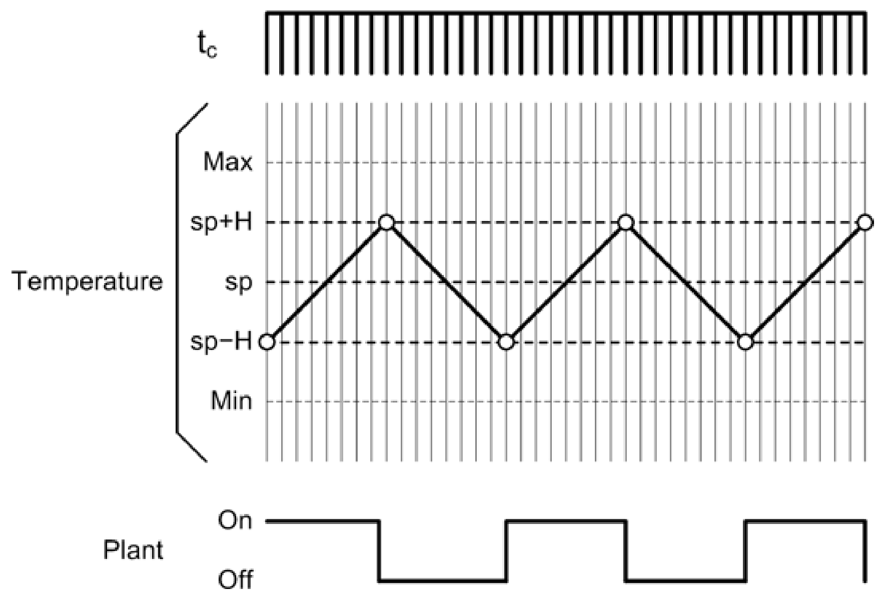


Figure 9-20. Bang-bang control response

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 Kp, Ki og Kd

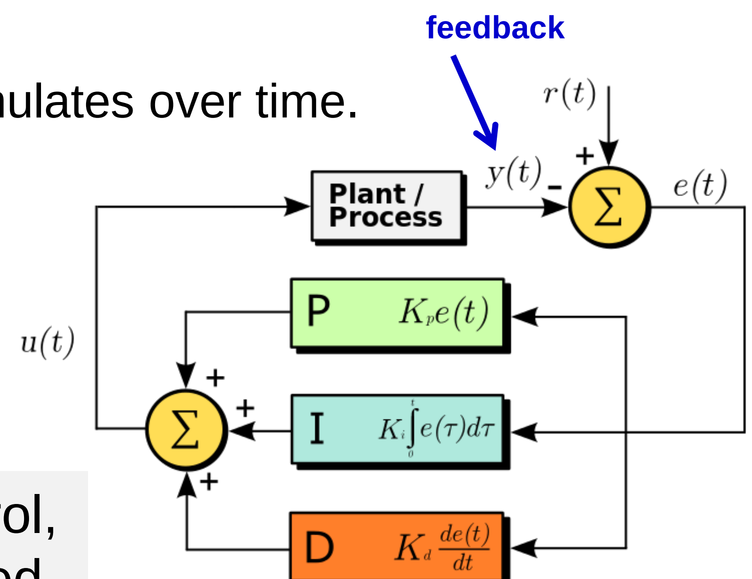


Figure from wikipedia

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

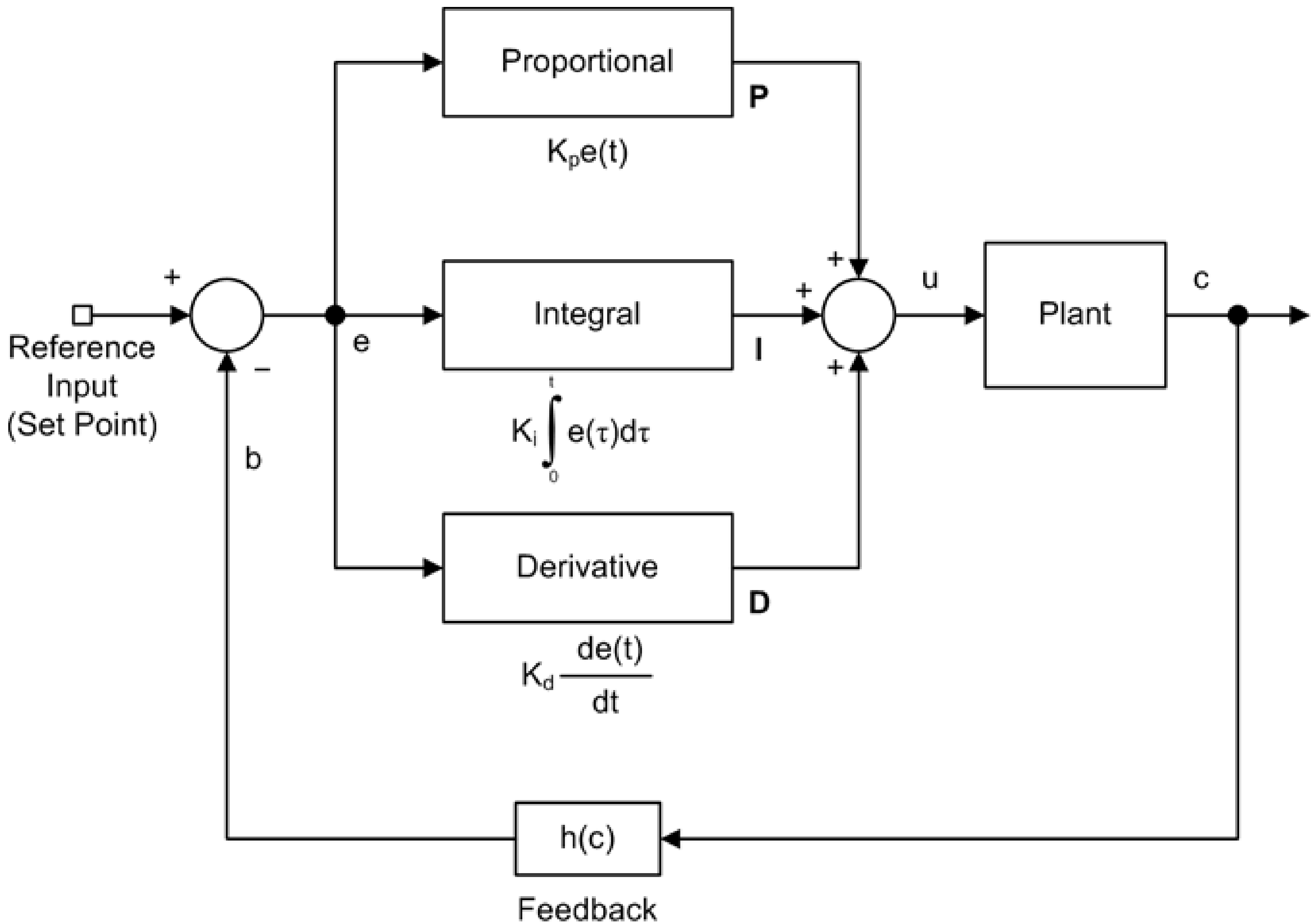
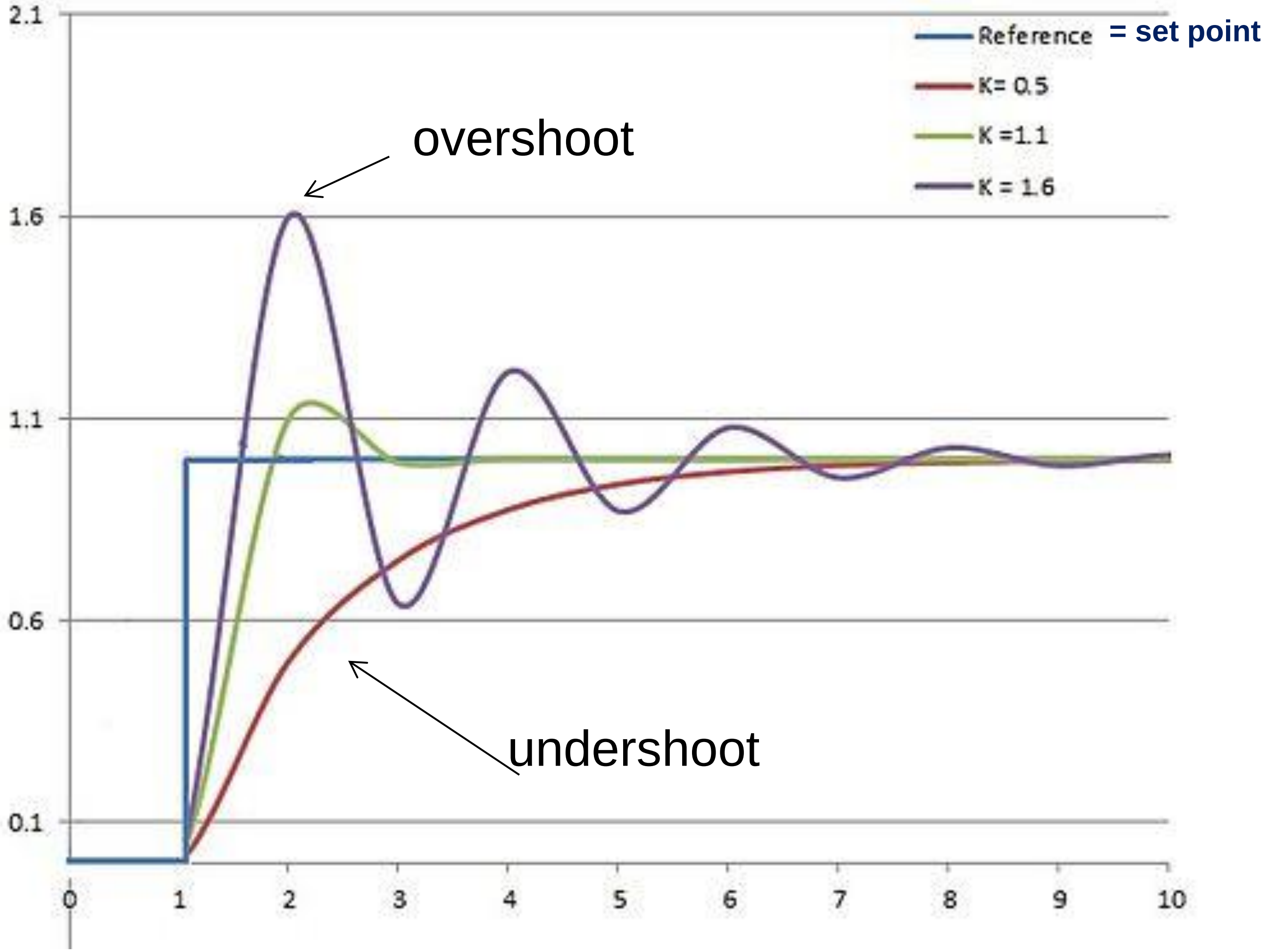


Figure 9-24. PID control block diagram

PID controller tuning examples



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.

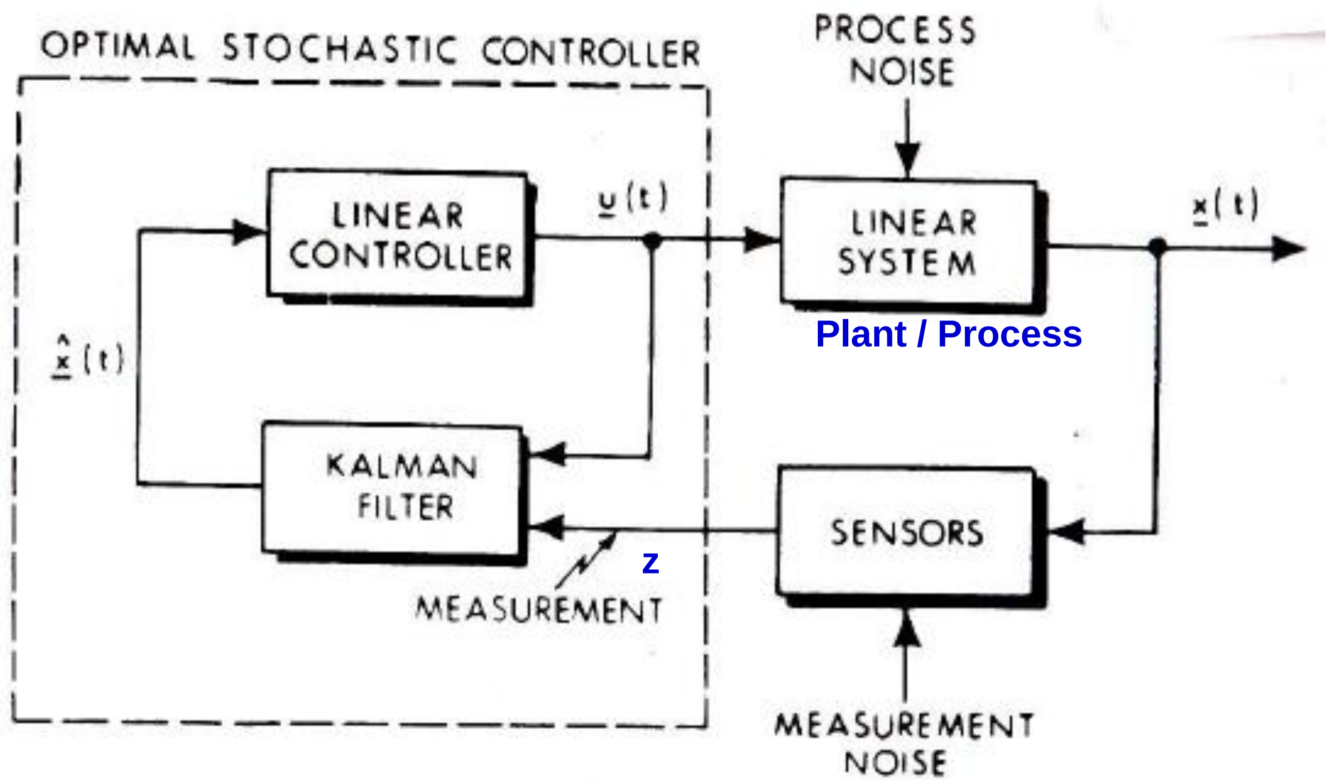


Figure from Gelb