EECE322-01: 자동제어공학개론

Introduction to Automatic Control

Chapter 1: Introduction

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◆ The main objectives of this chapter are

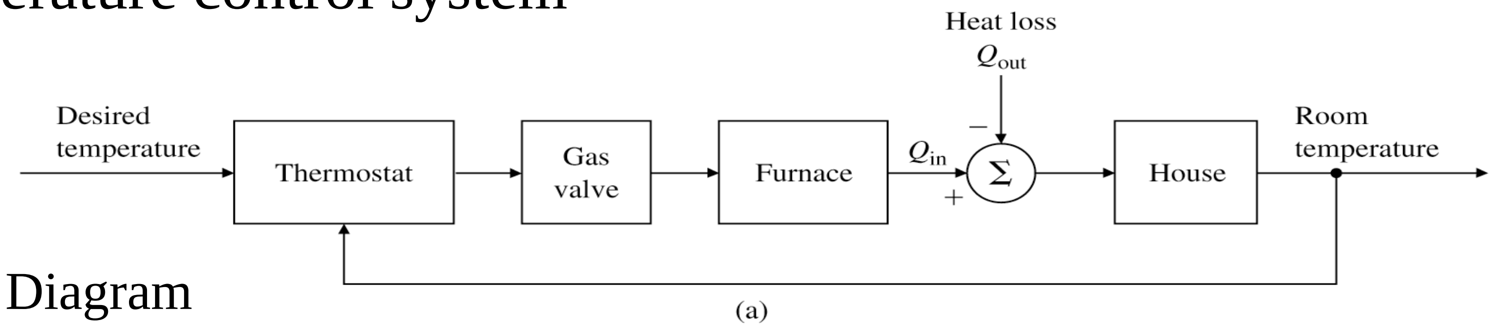
1. Brief introduction to feedback systems

2. Brief history of control engineering

1. Brief Introduction to Feedback Systems

Example of control system

- A room temperature control system



Block Diagram

- System
- Plant
- Actuator
- Sensor
- Feedback
- Closed-loop system

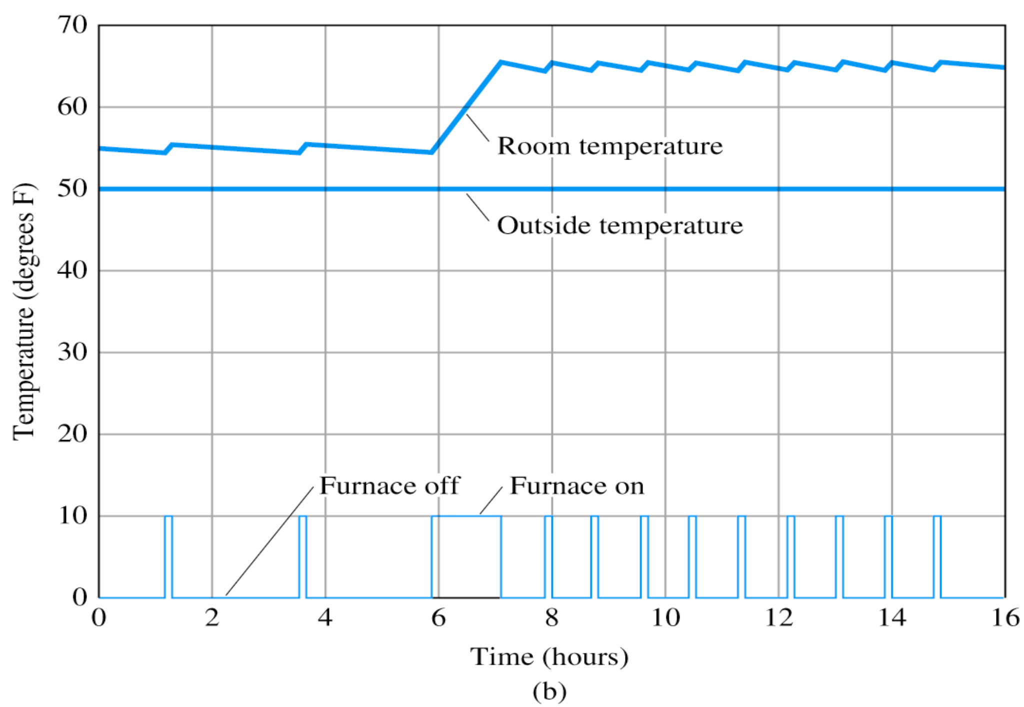


Figure 1.1 (a) Component block diagram of a room temperature control system (b) Plot of room temperature and furnace action

Key elements of feedback control systems

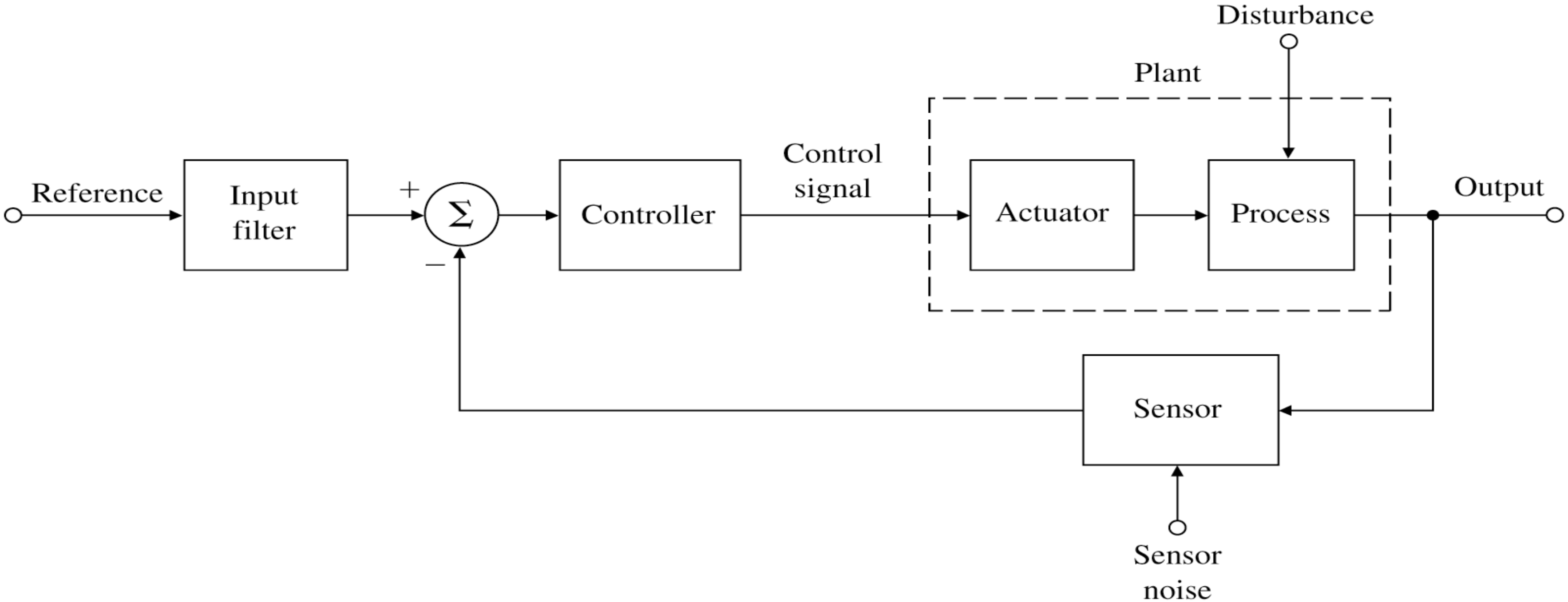


Figure 1.2 Component block diagram of an elementary feedback control

- Plant= process + actuator
- Sensor: location, which variable
- Model uncertainty, sensor noise, disturbance

Analysis of feedback – example of cruise control

- Cruise control of an automobile
  -a simple example to examine the effectiveness of a feedback control

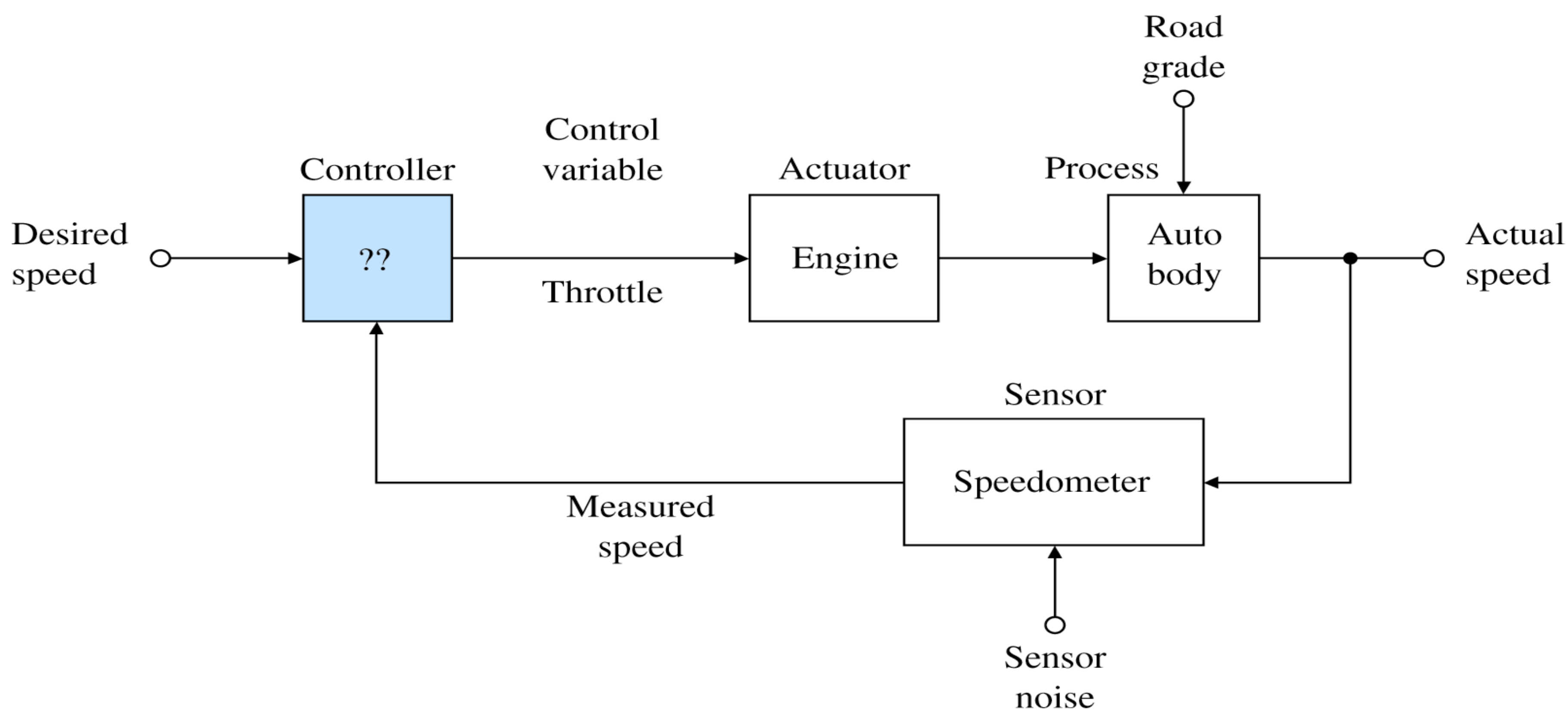


Figure 1.3 Component block diagram of automobile cruise control

Mathematical model

- Mathematical model for cruise control plant (steady-state model)

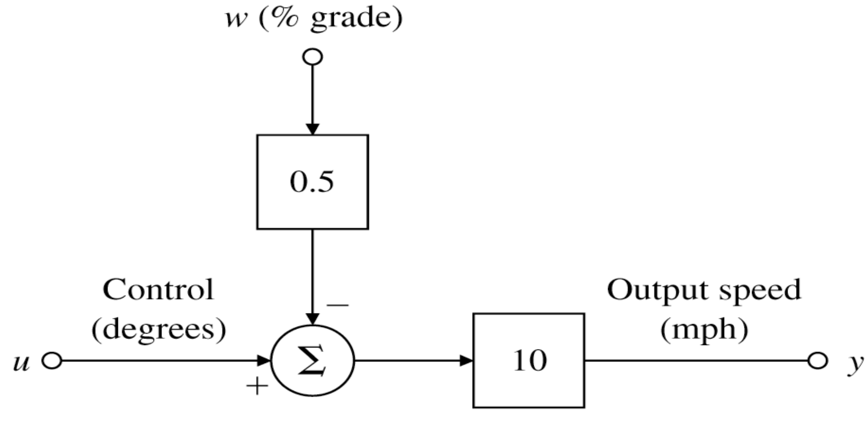


Figure 1.4 Block diagram of the cruise control plant

- Measured: on a level road at 65 mph, (10-mph change)/(1° in throttle angle)

on down/uphills, $(+/-)$ 5-mph/(1% grade change)

- Approximate the relation as linear

- Assume that the speedometer is exact (no sensor noise)

$$y_{ol} = 10u - 5w = 10(u - 0.5w)$$

u : throttle angle (deg)

w : road grade (%)

$(Note$: 65 mph at throttle angle u_{65}(deg) $\rightarrow$ $y_{ol} = 65 + 10(u - u_{65}) - 5w)$

Open-loop system

- Open-loop cruise control

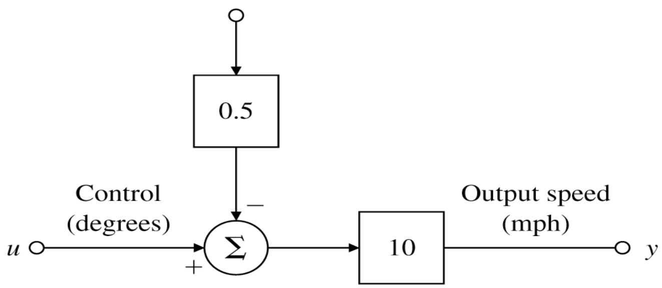


Figure 1.4 Block diagram of the cruise control plant

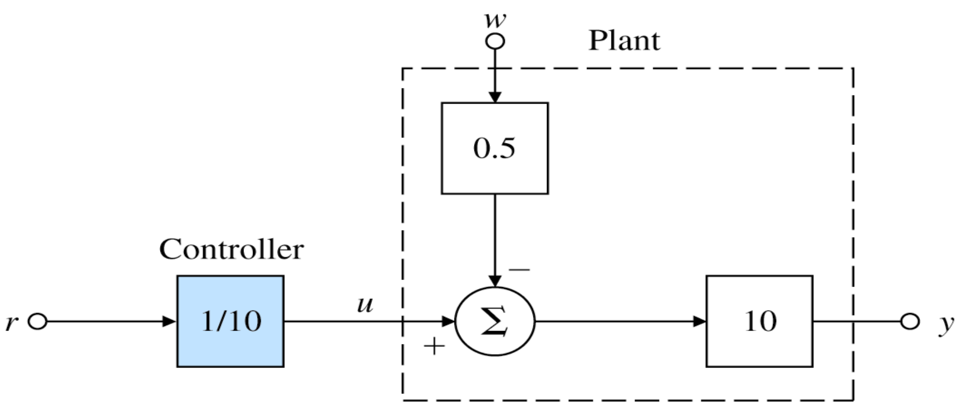


Figure 1.5 Open-loop cruise control

$$\text{(output speed) } y_{ol} = 10(u - 0.5w) = 10(0.1r - 0.5w) = r - 5w$$

$$\text{(error in output speed) } e_{ol} = r - y_{ol} = 5w$$

$$\%\ \text{error} = 100 \times \frac{y_{ol}\big|_{w=0} - y_{ol}}{y_{ol}\big|_{w=0}} = 100 \times \frac{5w}{r} = 500\frac{w}{r}$$

$$\text{At } r = 65: \qquad w = 1 \rightarrow y_{ol} = 60,\ \ \%\ \text{error} = 100\frac{5}{65} = 7.69$$

$$w = 2 \rightarrow y_{ol} = 55,\ \ \%\ \text{error} = 100\frac{10}{65} = 15.38$$

Closed-loop system

- Closed-loop cruise control

$$\boxed{\text{Feedback gain}: K = 10}$$

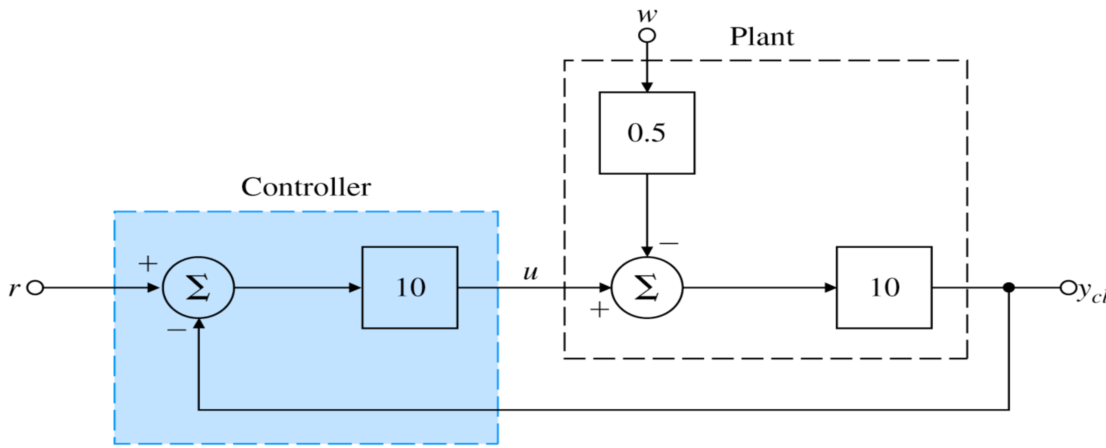


Figure 1.6 Closed-loop cruise control

$$y_{cl} = 10u - 5w, \; u = 10(r - y_{cl})$$

$$y_{cl} = 10\big(10(r - y_{cl})\big) - 5w \Rightarrow \; y_{cl} = \frac{100}{101} r - \frac{5}{101} w$$

$$e_{cl} = r - y_{cl} = \frac{r}{101} + \frac{5w}{101} \; (Note: 101 = K \times 10 + 1)$$

$$\text{(steady-state error) } w = 0 \rightarrow y_{cl} = \frac{100}{101} r = 0.99r, \; e_{cl} = \frac{r}{101} = 0.01r$$

$$\text{(reduction of sensitivity to disturbance) } r = 65 \text{ mph}, \; w = 1$$

$$\rightarrow \% \text{ error} = 100 \times \frac{y_{cl}\big|_{w=0} - y_{cl}}{y_{cl}\big|_{w=0}} = 100 \times \frac{\left(\frac{100}{101} \cdot 65 - \left(\frac{100}{101} \cdot 65 - \frac{5}{101} \cdot 1\right)\right)}{\frac{100}{101} \cdot 65} = 0.0769 \; \%$$

Brief summary of feedback

- Feedback control results in
  - reduction of sensitivity to disturbances
  - reduction of plant gain $(\frac{y}{r})$ $(Note: 1 \rightarrow \frac{100}{101} = \frac{10\times10}{101})$
  - steady state error (can be removed by using integral control. [Ch 4])

$(Note: \ K = 10 \rightarrow K = 100 \rightarrow K = 1000\,?)$

- As the feedback gain increases, the steady state error decreases.
- A large feedback gain can make the system unstable.
- Performance considerations in controller design:
  - command following
  - disturbance rejection
  - insensitivity to sensor noise
  - insensitivity to modeling errors

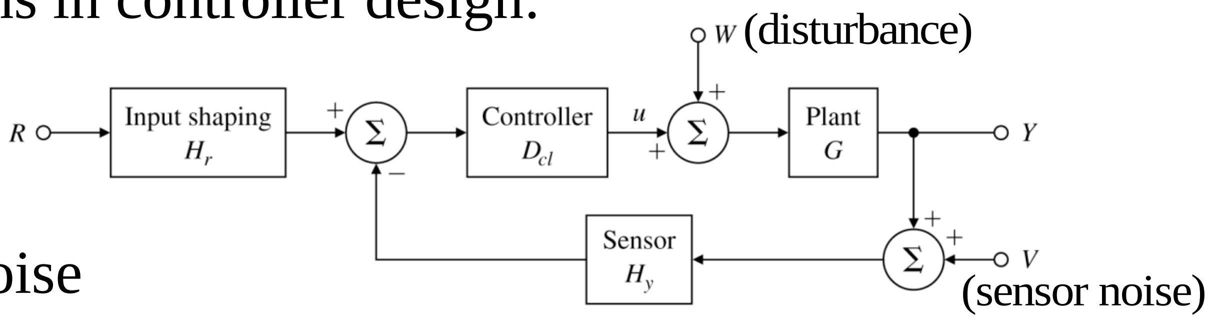


Figure 4.26 Basic feedback control block diagram

2. Brief History of Control Engineering

Example: water level control

- Liquid level and flow
  - control of flow rate to regulate a water clock
  - control of liquid level in a wine vessel
  - control of flow in the water tank of the flush toilet

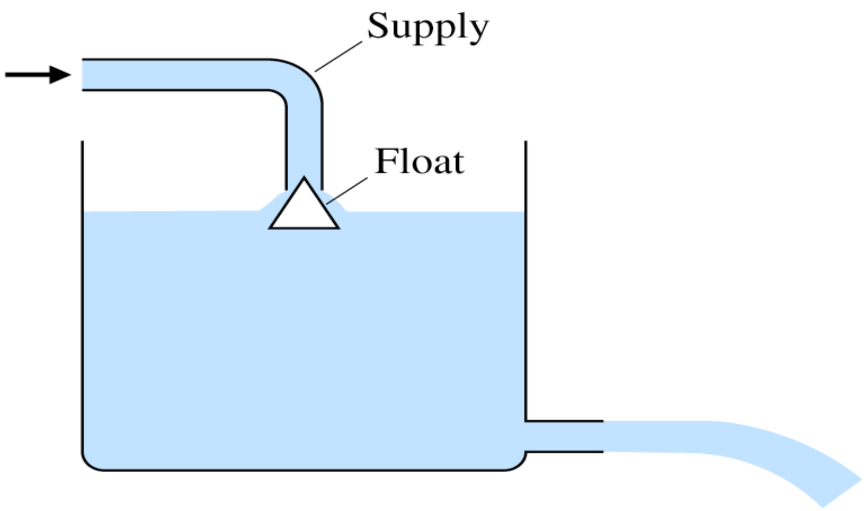


Figure 1.7 Early historical control of liquid level and flow

Example: temperature control

- Drebbel's incubator
  - control the temperature of a furnace
  - desired temperature: the length of riser

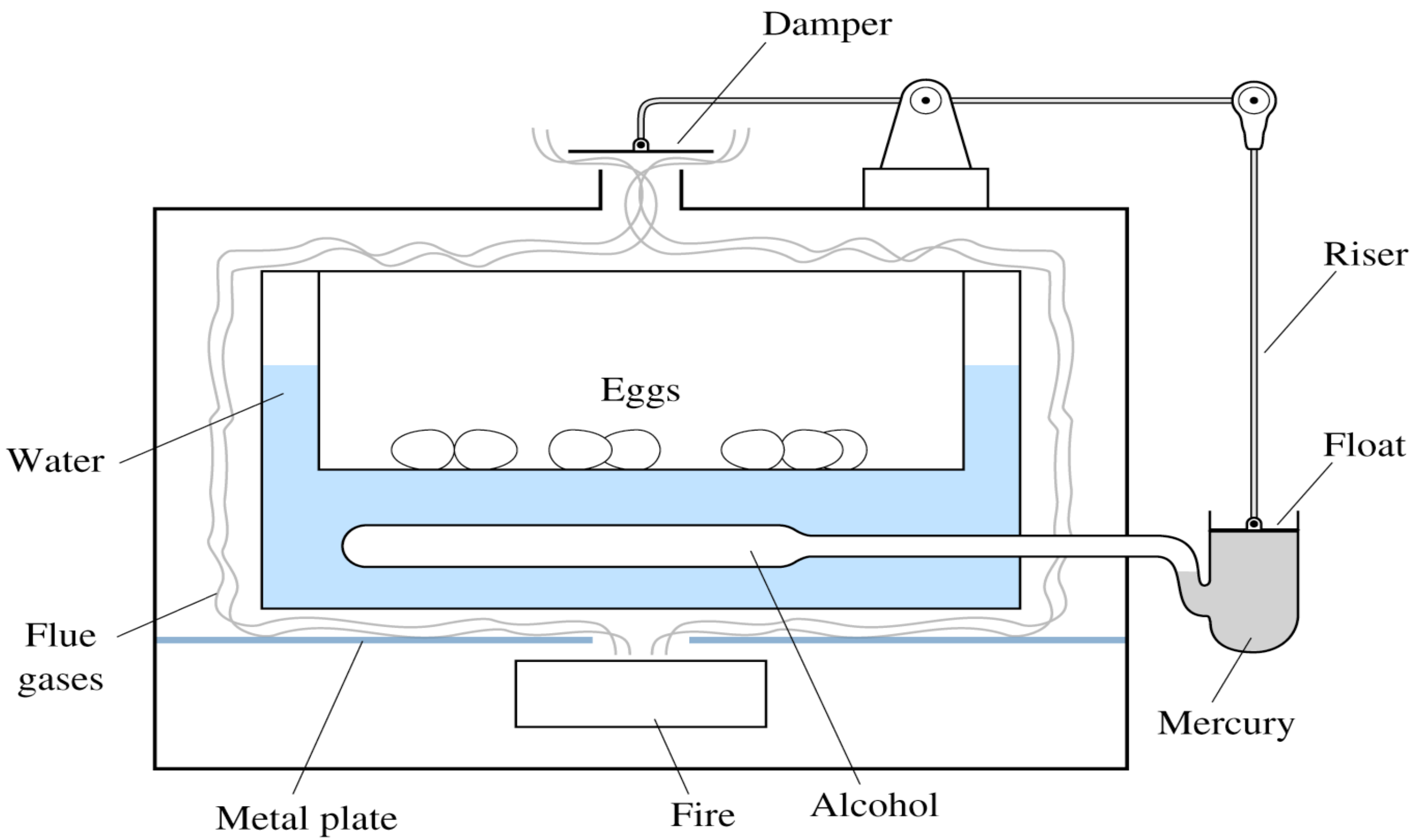


Figure 1.8 Drebbel's incubator for hatching chicken eggs. *(Adapted from Mayr, 1970)*

Brief history of control

- Beginnings

  Airy (1805-881): instability of feedback systems using differential equations

- Stability analysis

  Maxwell (1868): first systematic study of stability of feedback systems

  Routh (1877): stability criterion based on the roots of the characteristic equation

  Lyapunov (1892): stability of motion based on non. diff. equations

- Frequency Response (feedback amplifier in long distance telephoning)

  Black (1927): invention of electronic feedback amplifier

  Nyquist (1932): Nyquist stability criterion (stability from a graphical plot of the loop frequency responses)

  Bode (1945): Bode plot

- PID control (feedback control of industrial processes)

  Callendar et al. (1936): proportional-integral-derivative control

- Root locus

  Evans (1948): graphical plot of roots of the characteristic equation with variable parameters

- State-variable design

  Bellman: Principle of optimality, Dynamic programming

  Kalman: Kalman filter

  Pontryagin: Maximum principle of optimality

  Lyaponov: Lyapunov stability

  Wiener: Theory of stochastic processes, Wiener filter

- Classical control (SISO, frequency response) vs. Modern control
- Optimal control, Robust control, Adaptive control, Nonlinear control, Intelligent control
- Filtering and Estimation, System identification
- Computer tools available:

  MATLAB, MATRIX-X, CEMTOOL