Fall 2022 (111-1)

控制系統
Control Systems

Unit 7A
Control System Design: Principles

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NTU-EE

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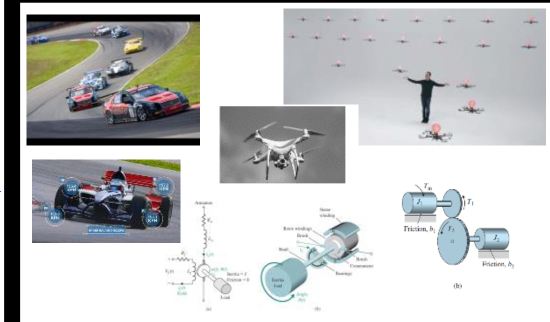
- Examples of Control Systems Design
  - Outline of Control Systems Design
  - Satellite’s Attitude Control
  - Lateral & Longitudinal Control of Boeing
  - Fuel–Air Ratio in an Automotive Engine
  - Read Write Head of a Hard Disk
  - RTP Systems in Wafer Manufacturing
  - Chemotaxis Swims Away from Trouble
  - Quadrotor Drone

- Control Tutorials Website
  - Cruise Control
  - Motor Speed
  - Motor Position
  - Suspension
  - Inverted Pendulum
  - Aircraft Pitch
  - Ball & Beam

Plant (P)

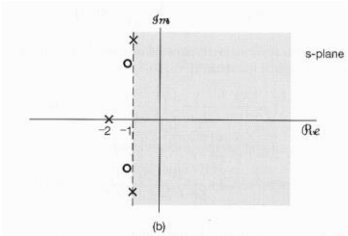


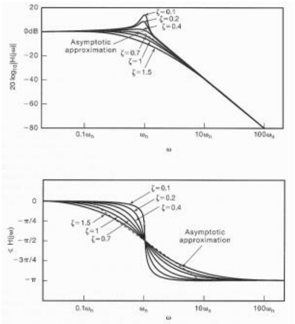
Signals & Systems

Ref (r) → Input (u) → Plant (P) → Output (y)

$$\frac{d^2y(t)}{dt^2} + 2\,\frac{dy(t)}{dt} - 3\,y(t) = 5\,u(t)$$

$$P(s) = \frac{Y(s)}{U(s)} = \frac{5}{s^2 + 2\,s - 3}$$





Control Systems

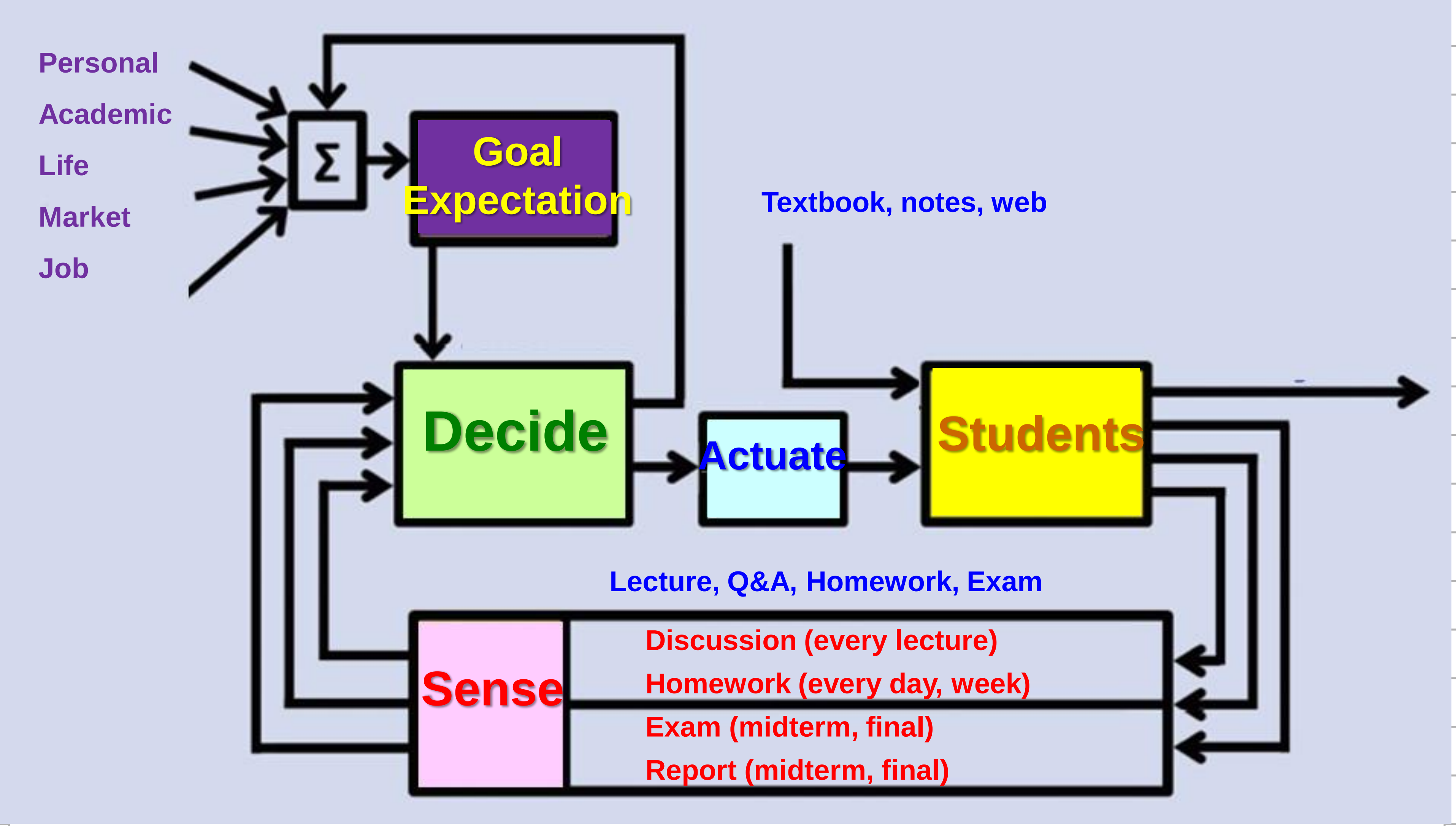
1. Model
2. Response
3. Analysis
4. Feedback
5. Control

Controller

$$\frac{d^2y(t)}{dt^2} + 4\,\frac{dy(t)}{dt} + 3\,y(t) = 3\,r(t)$$

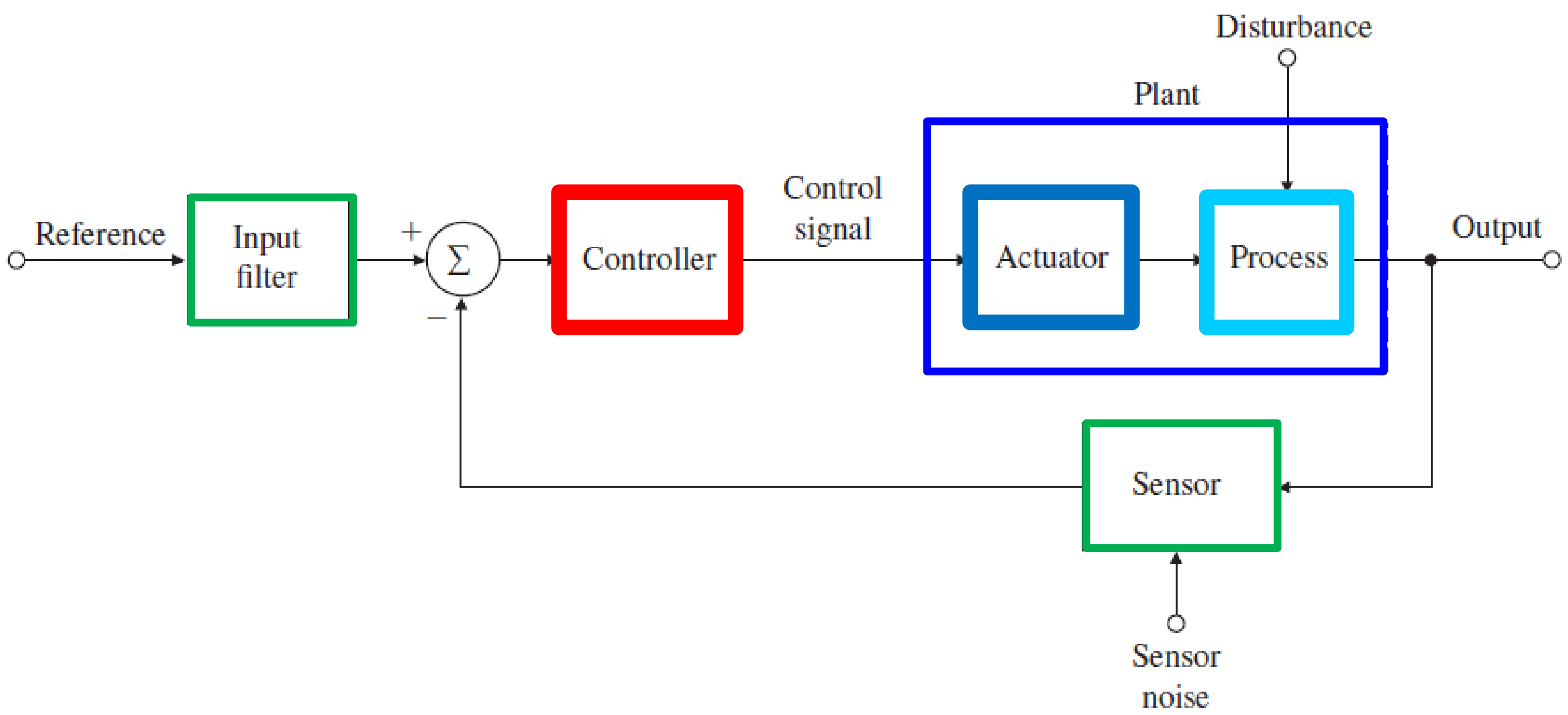
$$G(s) = \frac{Y(s)}{R(s)} = \frac{3}{s^2 + 4\,s + 3}$$

Feedback and Control in Teaching and Learning



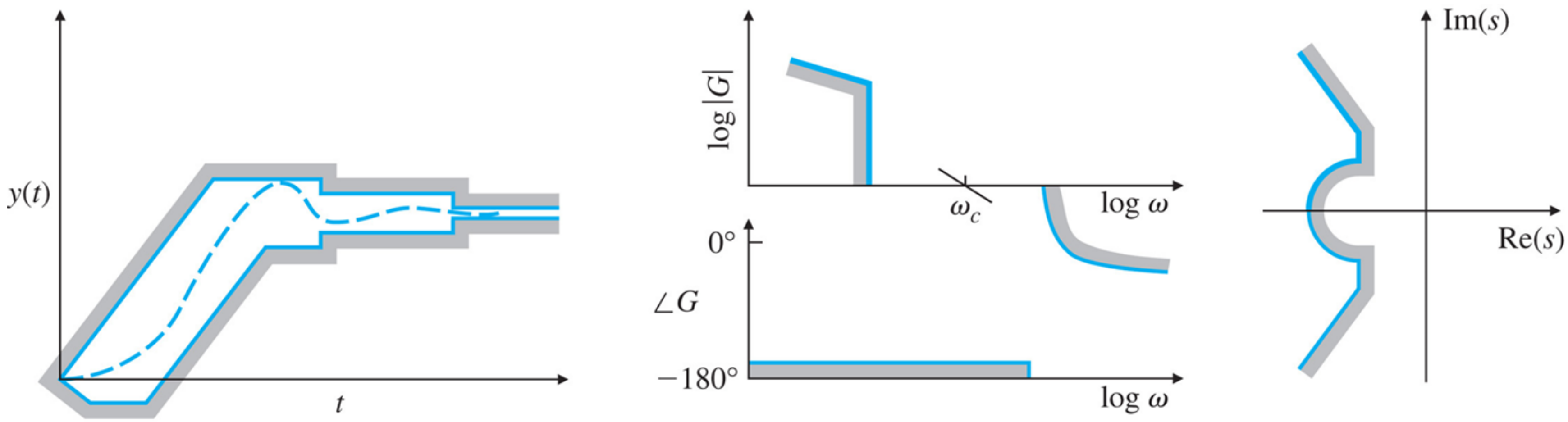
Source：IEEE CSM 2013

Key Terminologies in Feedback and Control



- (Step 1)
- Understand the Process and
- Translate Dynamic Performance Requirements
  into time, frequency, or pole-zero specifications.

  – Step response inside some constraint boundaries
  – Open-loop frequency response satisfying certain constraints
  – Closed-loop poles to the left of some constraint boundary



(a) (b) (c)

- (Step 2)
- Select Sensors

  – Select the types and number of sensors considering location, technology

Number of sensors and locations:	Select minimum required number of sensors and their optimal locations
Technology:	Electric or magnetic, mechanical, electromechanical, electro-optical, piezoelectric
Functional performance:	Linearity, bias, accuracy, bandwidth, resolution, dynamic range, noise
Physical properties:	Weight, size, strength
Quality factors:	Reliability, durability, maintainability
Cost:	Expense, availability, facilities for testing and maintenance

- (Step 3)
- Select Actuators

  – The device that influences the response is the actuator

  – Select the types and number of actuators considering location, technology, noise, and power

Number of actuators and locations:	Select minimum required actuators and their optimal locations
Technology:	Electric, hydraulic, pneumatic, thermal, other
Functional performance:	Maximum force possible, extent of the linear range, maximum speed possible, power, efficiency, etc.
Physical properties:	Weight, size, strength
Quality factors:	Reliability, durability, maintainability
Cost:	Expense, availability, facilities for testing and maintenance

- (Step 4)
- Construct a Linear Model
  - Construct a linear model of the process, actuator, and sensor

- (Step 5)
- Try a simple PID or Lead-Lag design
  (Proportional-Integral-Derivative)
  - Try a simple trial design
    based on the concepts of lead-lag compensation or PID control

- (Step 6)
- Evaluate / Verify Plant
  - Consider modifying the plant itself for improved closed-loop control

- (Step 7)
- Try an Optimal Design (State Space design) <Not Included>
  - If the performance from the simple compensator in Step 5 is not adequate,
    Perform a trial pole-placement design based on optimal control or other criteria

- (Step 8)
- Build a Computer Model, and
  Compute (Simulate) the Performance of the Design
  - Simulate the design, including the effects of nonlinearities, noise, and parameter variations.
  - If the performance is not satisfactory, return to Step 1 and repeat.
  - Consider modifying the plant itself for improved closed-loop control

- (Step 9)
- Build a Prototype