[MEN573] Advanced Control Systems I

Lecture 1 – Introduction

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Overview

- MEN573 is about analysis and control techniques for linear dynamic systems.
- It is a pre-requisite to most control graduate courses offered by the department.
- It is assumed that you have taken at least one undergraduate control course.
- **MEN573 covers a lot of material at a fast pace.**

Introduction

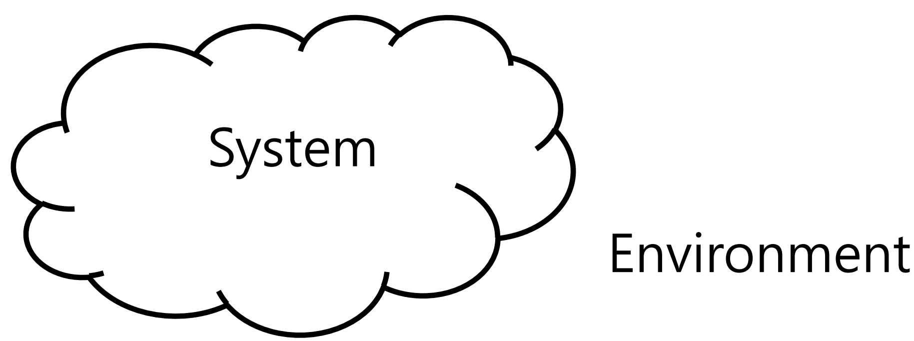
- **MEN573:** Analysis and **control** of linear dynamical systems

- **Control System:** Any system that exists for the purpose of controlling the flow of energy, information, or any other quantity in some *desired fashion*
  - *Regulation:* maintaining a steady state value
  - *Tracking:* following some reference or prescribed trajectory

Introduction

- **MEN573:** Analysis and control of linear dynamical **systems**

- **System:** A collection of “matter” contained within a real or imaginary boundary or surface
- **Environment**: all that is outside the system



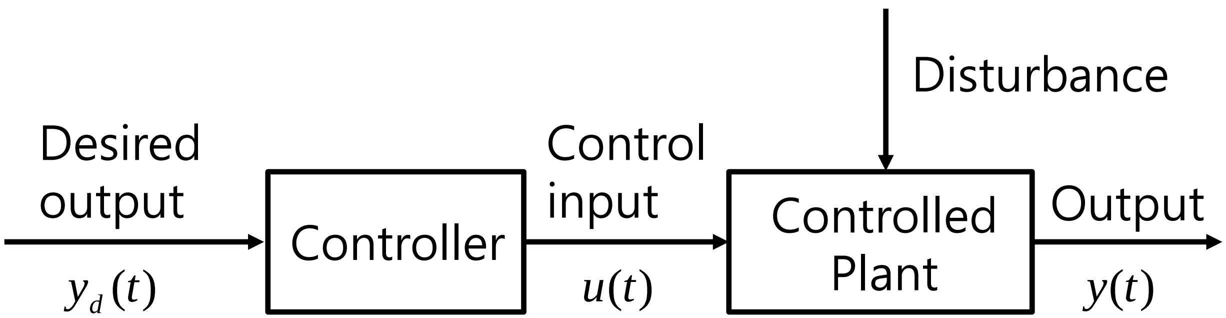
Introduction

- Objectives of control include:
  - Better stability
  - Regulation of output in the presence of disturbance and noises
  - Tracking time varying desired outputs
  - …

- To achieve these objectives, the control engineer must
  - Model controlled plants
  - Analyze characteristics of plants
  - Design controllers
  - Examine whether the designed controlled meets specifications (simulation, etc.)
  - Implement the controller

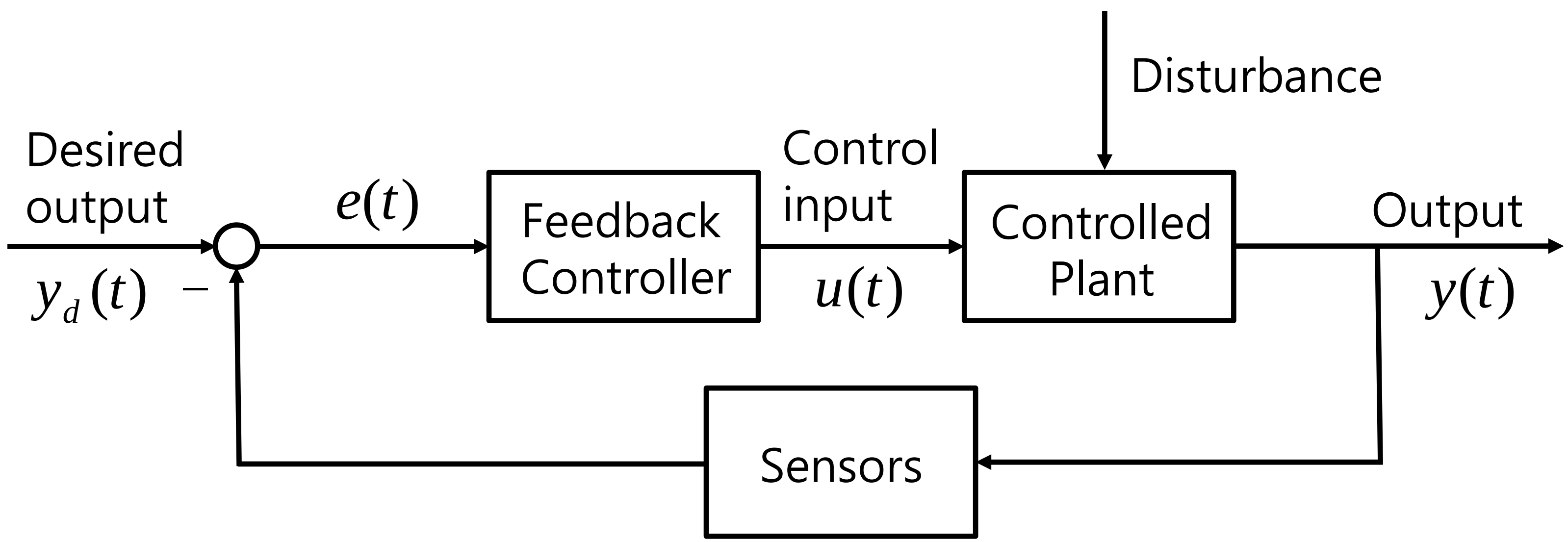
Open Loop Control vs. Closed Loop Control

- Open Loop Control System



Open Loop Control vs. Closed Loop Control

- Closed Loop (Feedback) Control System



Open Loop Control vs. Closed Loop Control

- Typical feedback controller (responding to the error)
  - The proportional plus Integral plus Derivative (PID) controller is a most frequently used feedback controller.

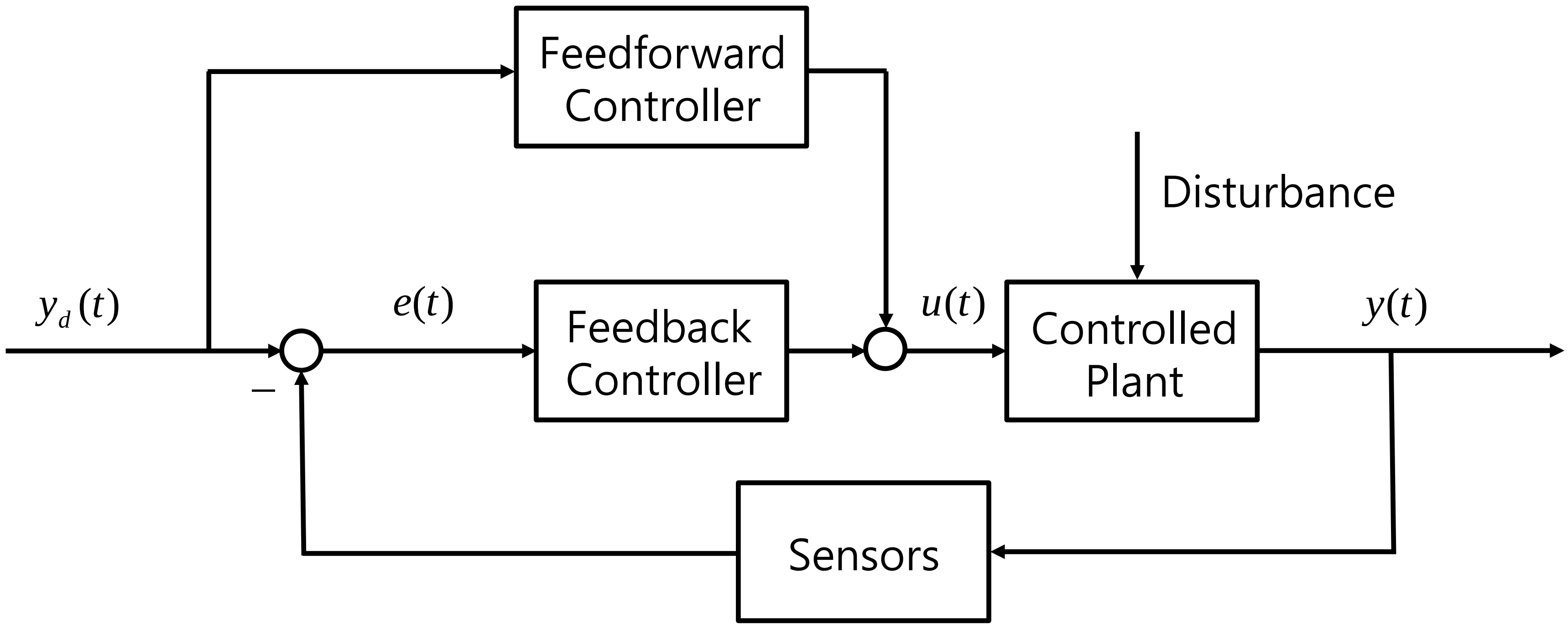
$$u(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_d \frac{de(t)}{dt}$$

Open Loop Control vs. Closed Loop Control

- Closed loop (feedback) controllers provide a **more robust performance** than open loop controllers in the presence of disturbances and plant uncertainties.

- One limitation of feedback control is that **the error must exist** for any control action to take place. This limitation can be overcome by adding a “feedforward” controller to the feedback control system.

Open Loop Control vs. Closed Loop Control



Static vs. Dynamic

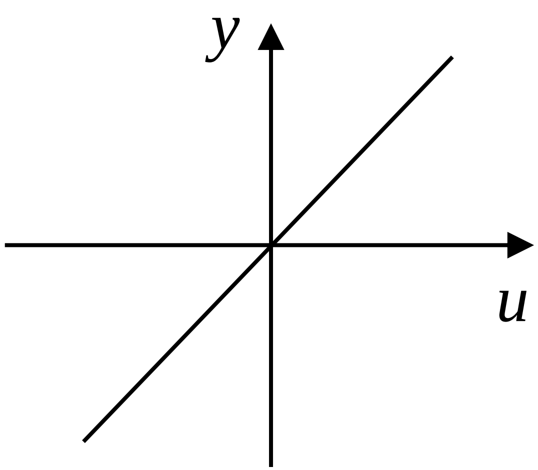
- The design of controllers is non-trivial because controlled plants (systems) are **dynamic**.
- **Static systems** and **dynamic systems**: the output of a static system depends on the present input only (memory-less), i.e. $y(t)=f(u(t))$; the output of a dynamic system depends on the past as well as present input (memory), $y(t)=f(u(\tau); \tau \leq t)$.
- The input-output relation of a static system is given by an **algebraic** equation.
- The input-output relation of a dynamic system is given by **differential/difference** equations.

Linear Systems vs. Nonlinear Systems

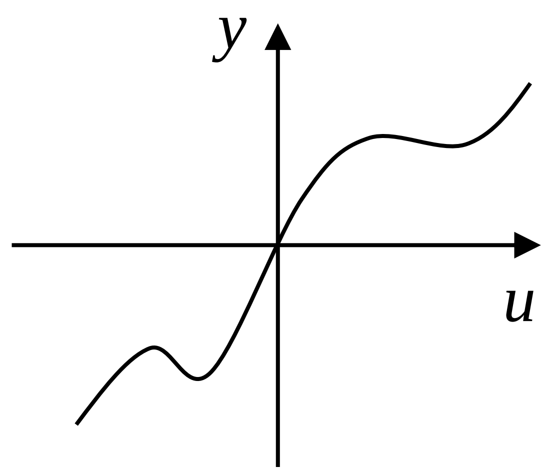
- The system is linear if it follows the **superposition principle**.
- If not, the system is nonlinear.

$$\{u_1(t),\ y_1(t)\}$$
$$\{u_2(t),\ y_2(t)\}$$

$$\Rightarrow \{\alpha u_1(t) + \beta u_2(t),\ \alpha y_1(t) + \beta y_2(t)\}$$



Static linear system



Static nonlinear system

Linear Systems vs. Nonlinear Systems

- In mechanical systems, torque limits of motors, nonlinear springs, Coulomb friction forces, etc. make systems nonlinear. Even if physical systems are nonlinear, they can often be linearized making linear analysis and design tools powerful. In this course, we **primarily consider linear systems and linear control**.

Causal Systems vs. Non-causal Systems

- A causal system is a system where the output depends on past and current inputs but not future inputs.
- A strictly causal system is a system where the output depends only on past inputs.
- A system that has some dependence on input values from the future (in addition to possible dependence on past or current input values) is a non-causal (acausal, anticausal) system.
- Causality, realizability

Continuous Time Systems vs. Discrete Time Systems

- Control engineers use computers extensively in both analysis/design (off-line) and implementation (real-time).

- Computers including micro-processors and DSPs are not expensive; furthermore they are more reliable and flexible than analog circuits, and digital implementation is common in many practical situation.

- This has made the **discrete time control theory** as important as the continuous time theory. This class will cover the both.

Continuous Time Systems vs. Discrete Time Systems

- In **continuous** time systems, inputs and outputs are defined for all t: i.e. u(t) and y(t).
- Continuous linear dynamic systems are described by linear **differential equations**.
- Example

$$m\frac{d^2y(t)}{dt^2}+b\frac{dy(t)}{dt}+ky(t)=u(t)$$

  - u(t)=force and y(t)=position of mass
  - m, b and k respectively the mass, damping coefficient and spring constant.

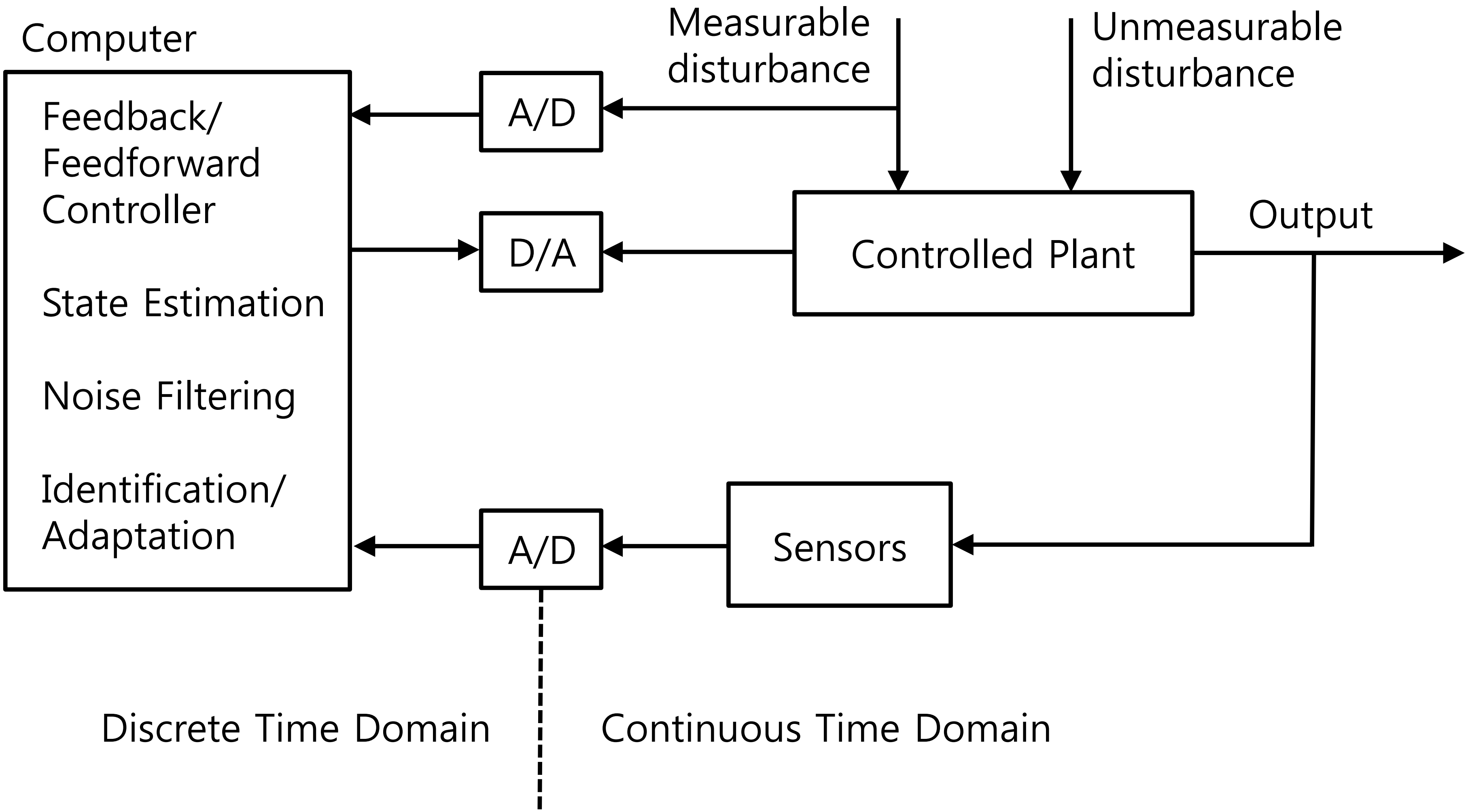
Continuous Time Systems vs. Discrete Time Systems

- In **discrete** time systems, inputs and outputs are defined at discrete time points: i.e. u(k) and y(k) are time sequences defined for k=0, 1, 2,…
- Discrete linear dynamic systems are described by linear **difference equations**.
- Example

$$x(k+1) = (1+\alpha)x(k) + u(k)$$

  - x(k)=balance at the beginning of k^{th} month
    u(k)=income
  - α is the interest rate.

Digital Control System



Development of Control Theory

- Linear classical control theory (frequency domain, 1950’s)
  - Based on Laplace transformation and transfer function
- State space theory (time domain, 1960’s)
  - Often called “modern” control as named when the theory was introduced. It is important to have good understanding on the relation between frequency domain and time domain.
- More recent developments (1970’s~)
  - Adaptive control and robust control deal with various uncertainties such as uncertain system parameters and neglected actuator/sensor dynamics.