EE 391

CONTROL SYSTEMS AND COMPONENTS

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Course Staff

- Instructor:
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- TAs:
- Office hours :
  - Saturday11:30-2:00PM

Basic Info.

- Textbooks
  - "Modern Control Systems", Richard Dorf, Robert Bishop
  - "Linear System Theory and Design", Third Edition, Chi-Tsong Chen
- Supplementary References
  - "Automatic Control Systems", Benjamin C. Kuo & F. Golnaraghi
- Prerequisites
  - Signals and Systems, and Linear Algebra
- Computer tools: MATLAB with control toolbox
- The Lab materials and assignments are developed with the aid of the following website:
  - http://ctms.engin.umich.edu/CTMS/index.php?aux=Home

Course Outline

- Introduction to control systems
- Mathematical modeling of control systems
- Block diagram representation of control systems
- Time-domain analysis of control systems
- The root-locus method
- Frequency-domain analysis
- State-space control methods

Course Work and Grading

- 5 Labs: Design and test different control techniques using Matlab
  - Lab work: 5 marks
  - Attendance: 5 marks
- 2 Projects: Choose between designing a simple control system or solving a Matlab assignment
  - 10 marks
- Homework: Submission and grading will be during the class periods
  - 10 marks
- A Midterm exam: 30 marks
- A Final Exam: 90 marks

Course Webpage

- All course materials and lecture slides will be published to the following website:

http://eng.alexu.edu.eg/~mmorsy/Courses/Undergraduate/EE391_Control_Systems_and_Components/EE391.html

- Announcements and course updates will be announced on the course webpage

Chapter 1

Introduction to Control Systems

"Modern Control Systems", Richard Dorf, Robert Bishop

Outline

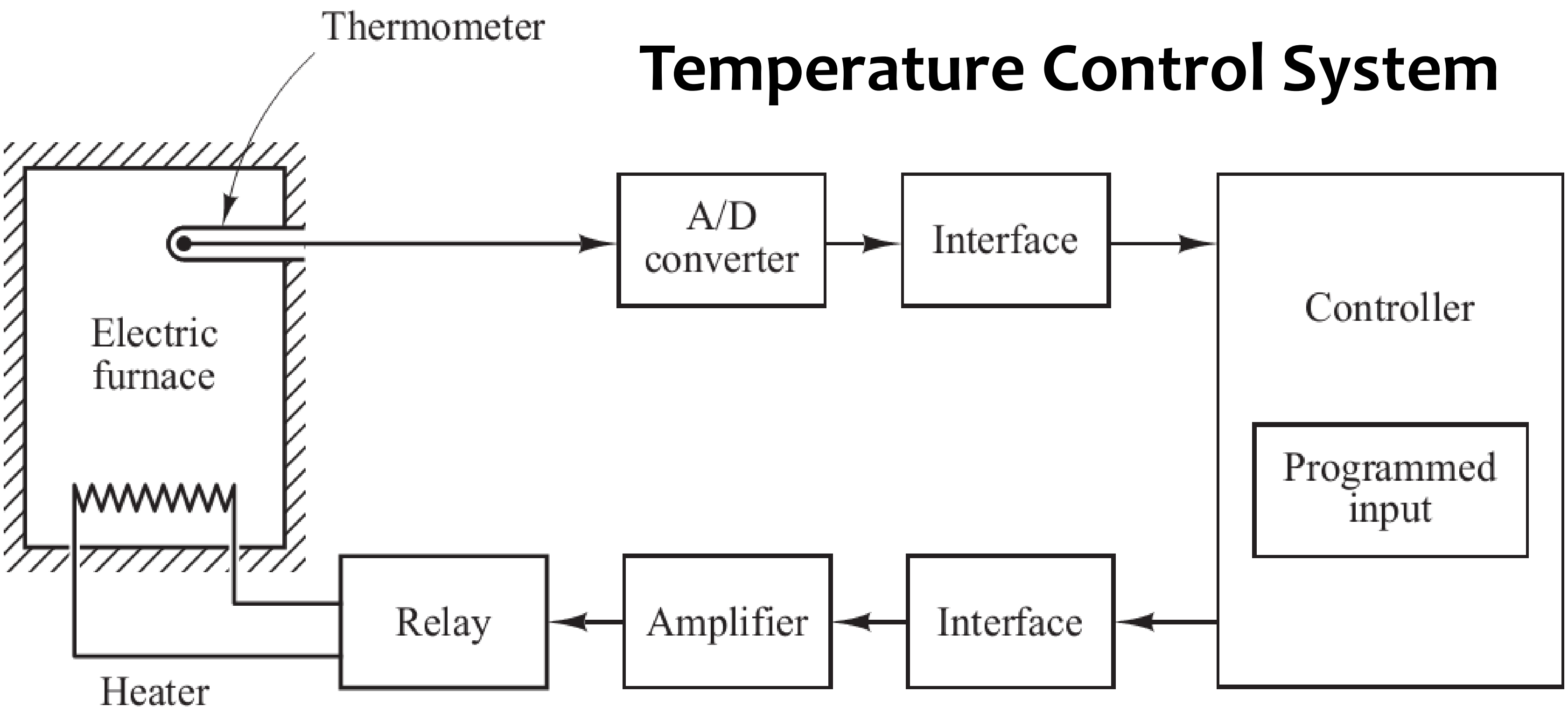
- Introduction
- Examples of Control Systems
- Control system components
- Open-loop control versus closed-loop control
- Classification of control systems
- Design procedures of control systems

Introduction

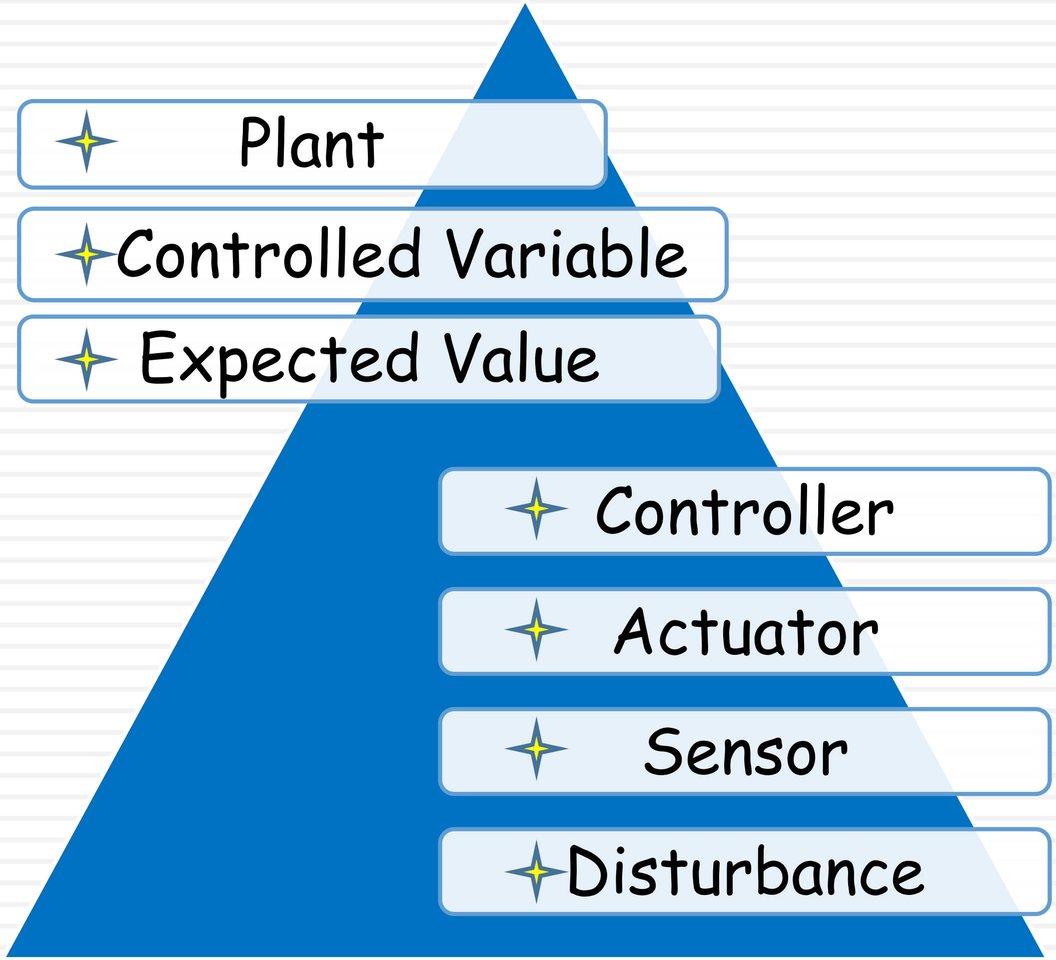
- Generally speaking, a control system is a system that is used to realize a desired output or objective.
- Control systems are everywhere
  - **They appear in our homes, in cars, in industry, in scientific labs, and in hospital…**
  - **Principles of control have an impact on diverse fields as engineering, aeronautics ,economics, biology and medicine…**
  - **Wide applicability of control has many advantages (e.g., it is a good vehicle for technology transfer)**

Examples of Control Systems

Temperature Control System



Basic Components of Control Systems



Basic Components of Control Systems (2)

Plant

1.Plant: a physical object to be controlled such as a mechanical device, a heating furnace, a chemical reactor or a spacecraft.

Controlled variable

2.Controlled variable: the variable controlled by Automatic Control System , generally refers to the system output.

Expected value

3.Expected value : the desired value of controlled variable based on requirement, often it is used as the reference input

Controller

4.Controller: an agent that can calculate the required control signal.

Actuator

5.Actuator: a mechanical device that takes energy, usually created by air, electricity, or liquid, and converts that into some kind of motion.

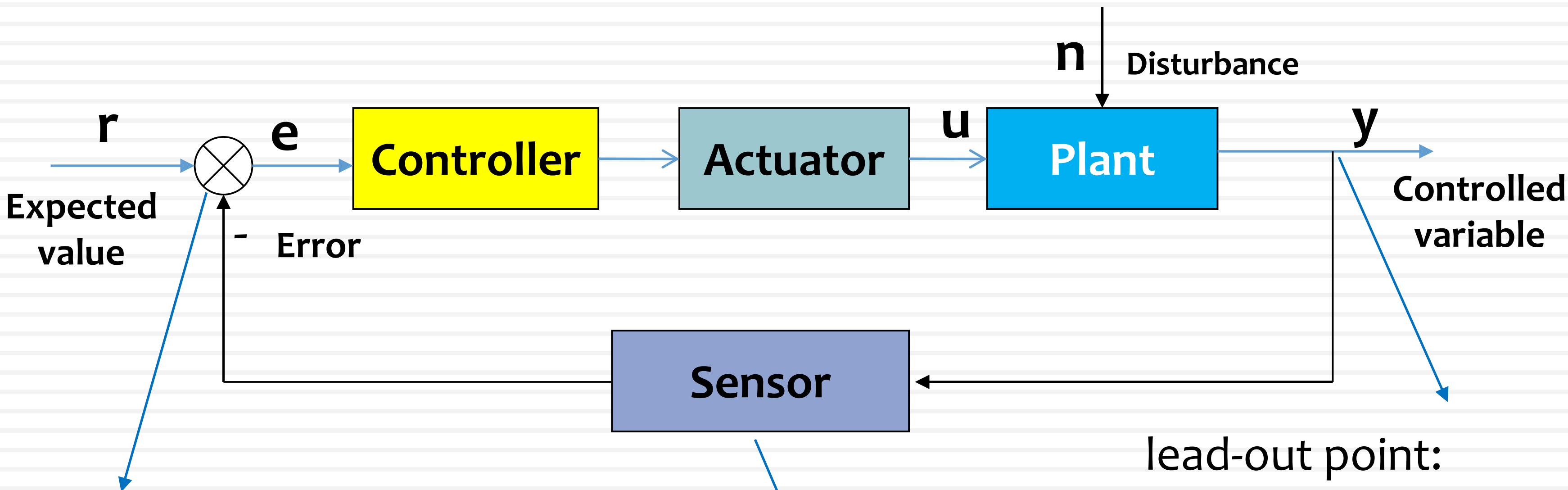
Sensor

6.Sensor : a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument.

Disturbance

7.Disturbance: the unexpected factors disturbing the normal functional relationship between the controlling and controlled parameter variations.

Block Diagram of a Control Systems



lead-out point:
Here, the signal is transferred along two separate routes.

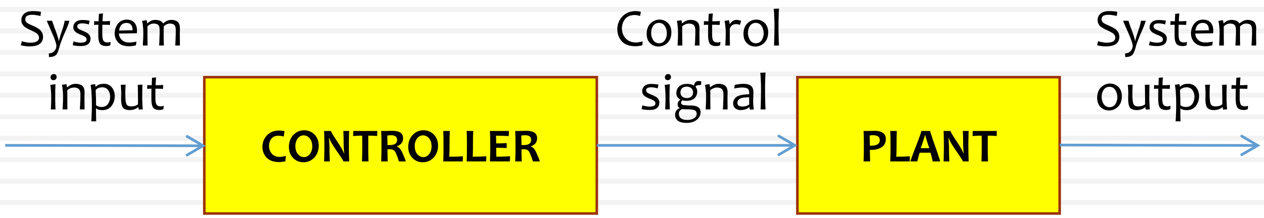
comparison component (comparison point) : its output equals the algebraic sum of all input signals.

"+": plus; "-": minus

The Block represents the function and name of its corresponding mode, we don't need to draw detailed structure, and the line guides for the transfer route.

Open-Loop Control systems

- Open-loop control systems: those systems in which the output has no effect on the control action.



- The output is neither measured nor fed back for comparison with the input.
- For each reference input, there corresponds a fixed operating conditions; the accuracy of the system depends on *calibration*.
- In the presence of *disturbances,* an open-loop system will not perform the desired task.

Open-loop Control Systems (2)

- Examples
  - Washing machine #Traffic signals

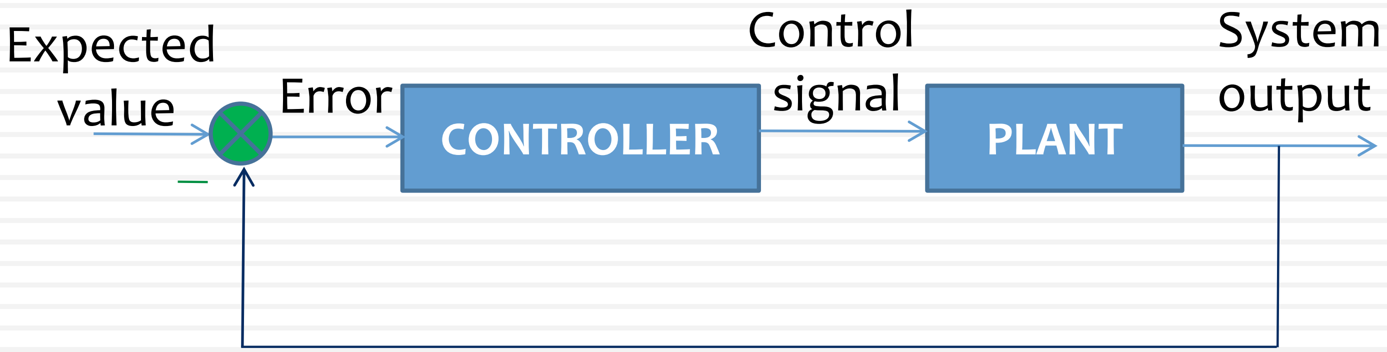
Note that any control systems that operates on a time basis are open-loop

Open-loop Control Systems (3)

- When should we apply open-loop control?
  - The relationship between the input and output is *exactly known*.
  - There are *neither* internal *nor* external disturbances.
  - Measuring the output precisely is *very hard* or *economically infeasible*.

Closed-loop Control Systems

- Closed-loop control systems are often referred to as feedback control systems.
- The idea of feedback:
  - Compare the *actual output* with the *expected value*.
  - Take actions based on the *difference (error)*.

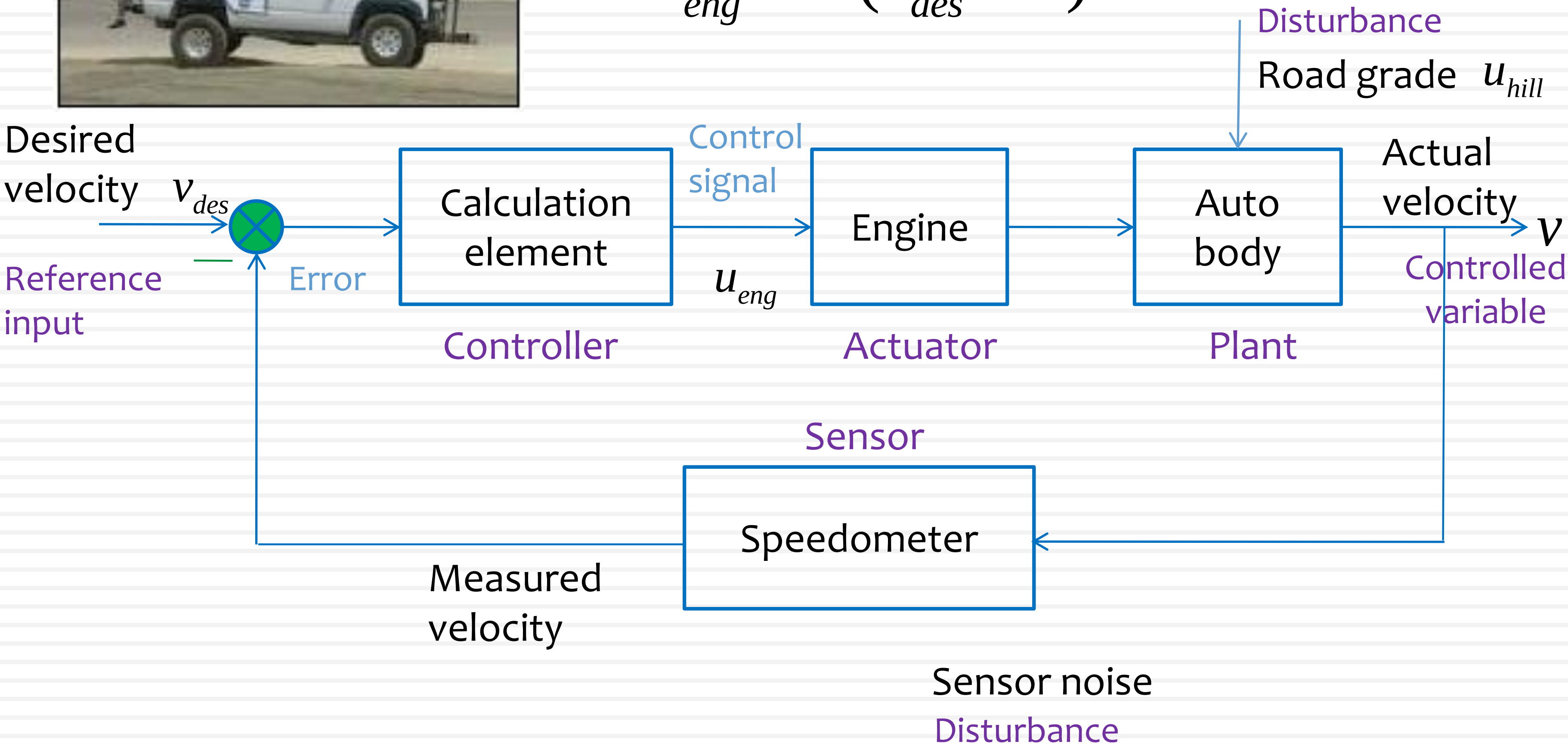


  - This seemingly simple idea is tremendously powerful.
  - Feedback is *a key idea* in the discipline of control

Example: Cruise Control

$$m\dot{v} = -bv + u_{eng} + u_{hill}$$

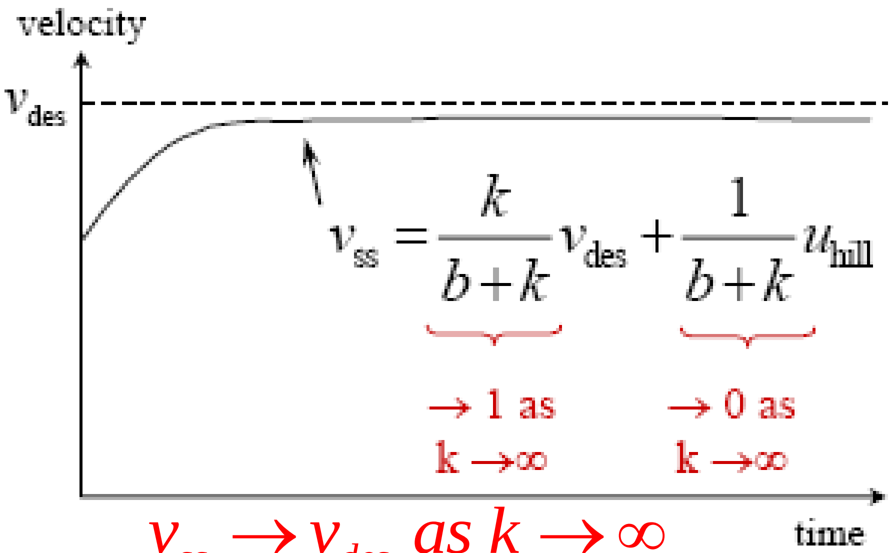
$$u_{eng} = k(v_{des} - v)$$



Example: Cruise Control (2)

$$m\dot{v} = -bv + u_{engine} + u_{hill}$$

$$u_{engine} = k(v_{des} - v)$$



$v_{ss} \rightarrow v_{des}$ as $k \rightarrow \infty$

- **Stability/performance**
  - Steady state velocity approaches desired velocity as $k \rightarrow \infty$;
  - Smooth response: no overshoot or oscillations
- **Disturbance rejection**
  - Effect of disturbances (eg, hills) approaches zero as $k \rightarrow \infty$
- **Robustness**
  - Results don't depend on the specific values of *b*, *m* or *k*, *for k sufficiently* large

Feedback control

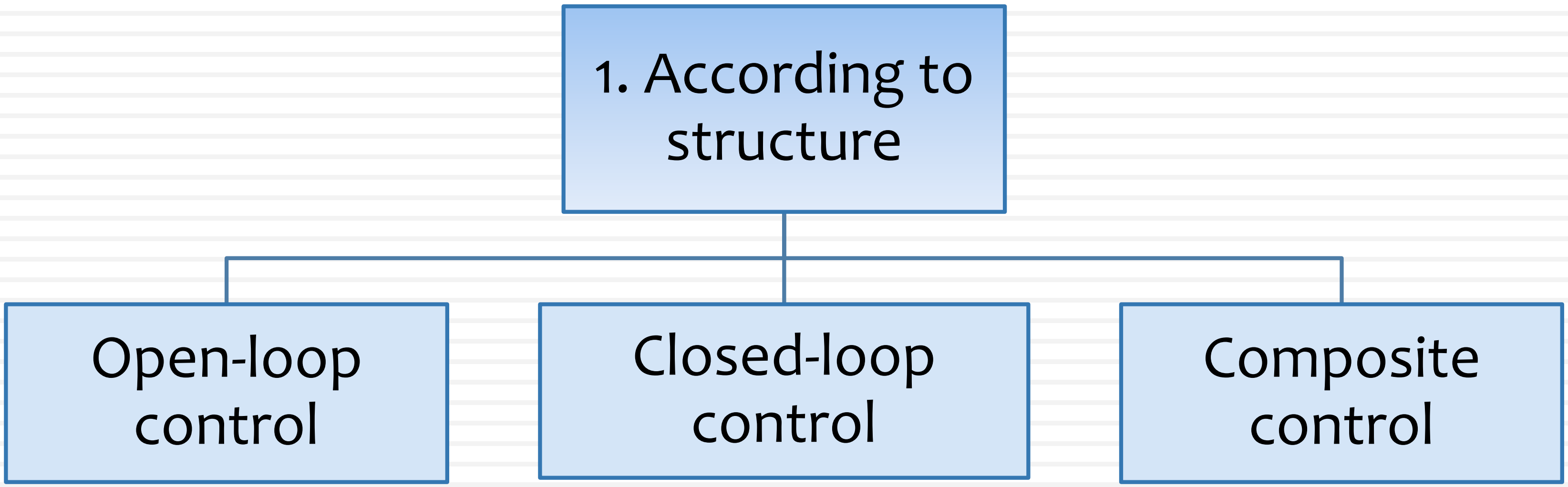
- Main advantages of feedback:
  - reduce disturbance effects
  - make system insensitive to variations
  - stabilize an unstable system
  - create well-defined relationship between output and reference
- Potential drawbacks of feedback:
  - cause instability if not used properly
  - couple noise from sensors into the dynamics of a system
  - increase the overall complexity of a system

Open-loop vs. Closed-loop

- Open-loop control
  - Simple structure, low cost
  - Easy to regulate
  - Low accuracy and resistance to disturbance
- Closed-loop control
  - Ability to correct error
  - High accuracy and resistance of disturbance
  - Complex structure, high cost
  - Selecting parameter is critical (may cause stability problem)

Open-loop + Closed-loop = Composite control system

Classification of Control Systems



Classification of Control Systems (2)

2. According to reference input

- Constant-value control
- Servo/tracking control
- Programming control

Constant-value control

- the reference input (expected value) is a constant value
- the controller works to keep the output around the constant value

e.g. constant-temperature control, liquid level control and constant-pressure control.

Servo/tracking control

- the reference input may be unknown or varying
- the controller works to make the output track the varying reference

e.g. automatic navigation systems on boats and planes, satellite-tracking antennas

Programming control

- the input changes according to a program
- the controller works according to predefined command

e.g. numerical control machine

Classification of Control Systems (3)

3. According to system characteristics

$$f(x_1) = y_1 \qquad f(x_2) = y_2$$

superposition principle

$$f(x_1 + x_2) = f(x_1) + f(x_2) = y_1 + y_2$$

Linear control system

- superposition principle applies
- described by linear differential equations

Nonlinear control system

- described by nonlinear differential equations

Classifications of Control Systems (4)

5. According to parameters

- Time-invariant system
  - The parameters of a control system are stationary with respect to time
- Time-varying system
  - System contain elements that drift or vary with time
  - e.g. Guided-missile control system, time-varying mass results in time-varying parameters of the control system

Remarks on Nonlinear Control Systems

- Quite often, nonlinear characteristics are intentionally introduced in a control system to improve its performance or provide more effective control.

  For instance, to achieve minimum-time control, an on-off (bang-bang or relay) type controller is used in many missile or spacecraft control systems

- There are no general methods for solving a wide class of nonlinear systems

Remarks on Digital Control Systems

- A digital control system refers to the use of a digital computer or controller in the system, so that the signals are digitally coded, such as in binary code.
- Digital computers provide many advantages in terms of size and flexibility.
  - The expensive equipment used in a system may be shared simultaneously among several control channels.
  - Digital control systems are usually less sensitive to noise.

Basic Requirements of Control Systems

- Basic requirements for control systems
  - **Stability**: refer to the ability of a system to recover equilibrium
  - **Quickness**: refer to the duration of transient process before the control system to reach its equilibrium
  - **Accuracy**: refer to the value of steady-state error when the transient process ends

  (Steady-state error=desired output – actual output)

Note:

- For a control system, the above three performance indices (stability, quickness, accuracy) are sometimes contradictory.
- In design of a practical control system, we always need to make a compromise.

Course Outcome

- This course is concerned with the analysis and design of control systems

Analysis	• System modeling, sensitivity and stability
Design	• Time-domain techniques (root-locus analysis); • Frequency-domain techniques (Bode plot, Nyquist stability theory) • State-space methods
Simulation	• Analysis and design using MATLAB