黄河水利职业技术学院
YELLOW RIVER CONSERVANCY TECHNICAL INSTITUTE

Principles of Automatic Control

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Welcome to contact me

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Course Description

- Lectures: 48 hours
- Grading:
  - Attendance
  - Homework
  - Class participation
  - Final examination
- Objectives:
  - Basic understanding of control systems
  - Engineering applications

Course Materials

- Slides / Lecture notes
- References:
  - 胡寿松主编，《自动控制原理》
  - 李俨主编，Principles of Automatic Control
  - Carlos A. Smith, Principles and Practice of Automatic Process Control
  - H. Bischoff, Process Control System
  - Curtis D. Johnson, Process Control Instrumentation Technology

CHAPTER 1

Introduction to Control Systems

Outline

Introduction to control systems

- Requirements:

  - Open-loop control vs. Closed-loop control

  - Feedback control

  - Block diagram

  - Components distinguishment,

    such as, System Input, Output,

    Controller, Plant, Sensor

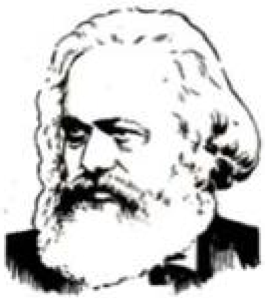
Introduction to control systems

- What is “Control” ?
- Development of “ Control Theory”
- Why to study “Automatic Control” ?
- What is “ Automatic Control” ?
- Feedback control structure
- Types of control systems
- Basic requirements on control systems

What is “Control” ?

- ”The philosophers have only interpreted the world, in various ways; the point is, however, to change it.”

  \- in 'Theses on Feuerbach', Karl Marx



- The capability of effective control is the unique characteristic distinguishing human beings and animals.

What is "Control" ?

- **Control:** *Action* on the system (machine, plant, process, ...) to *modify* (improve) its behavior according to desired requirements.
- **A Control system** consisting of interconnected components is designed to achieve a desired purpose.

Imagine "control" around you!

Room temperature control
Car driving
Voice volume control
"Control" (move) the position of the pointer etc.

Control ... everywhere!

- Energy generation and distribution





Control … everywhere!

- Process control

Control … everywhere!

- Manufacturing industry

Control ... everywhere!

- Vehicle control

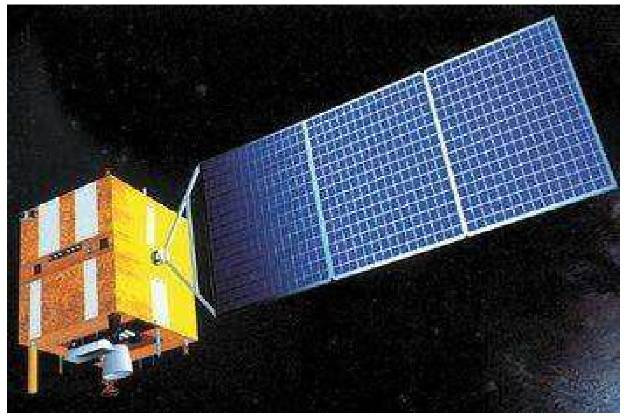
Control ... everywhere!

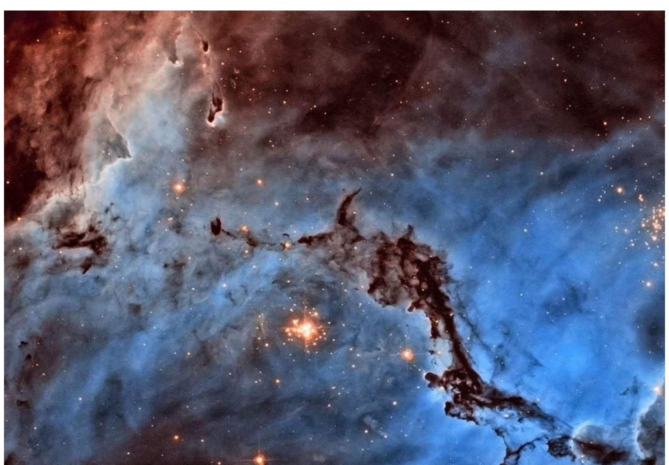
- Consumer Electronics



Control ... everywhere!

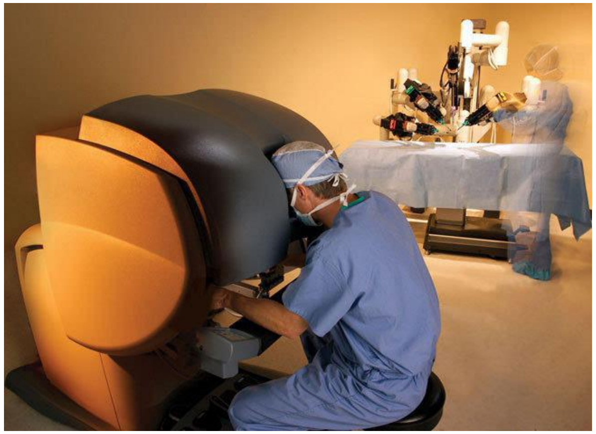
- Aeronautics

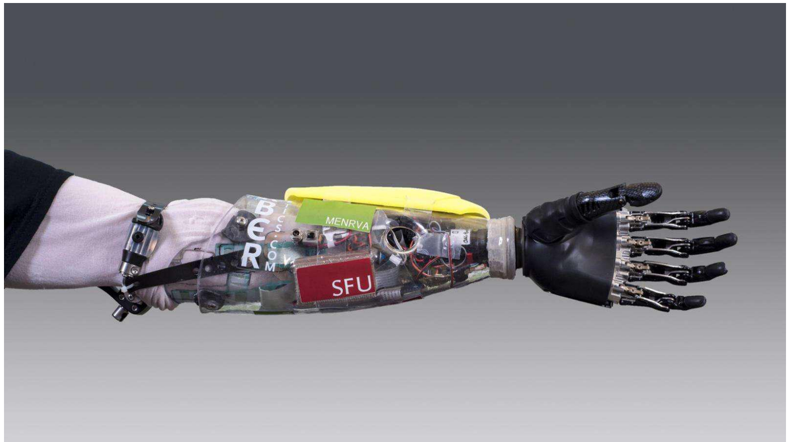




Control ... everywhere!

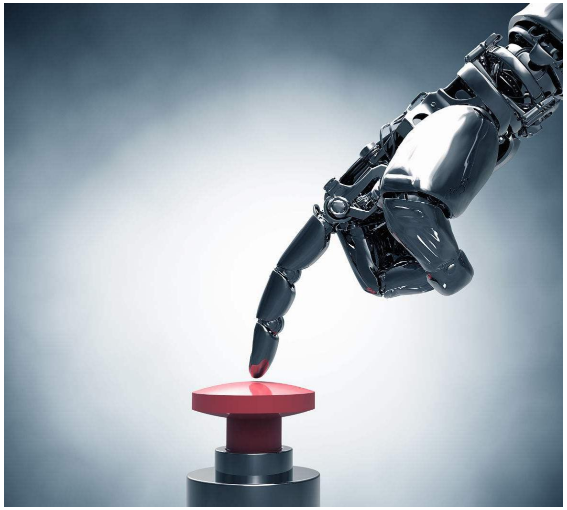
- Medical applications

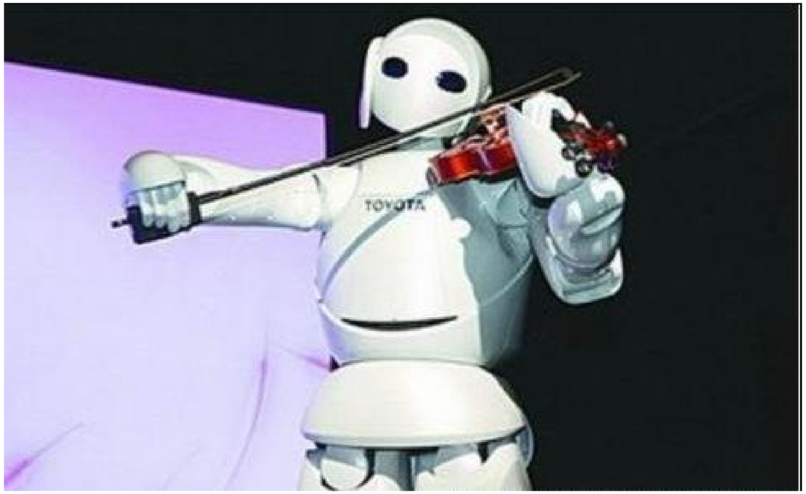




Control ... everywhere!

- Robotics



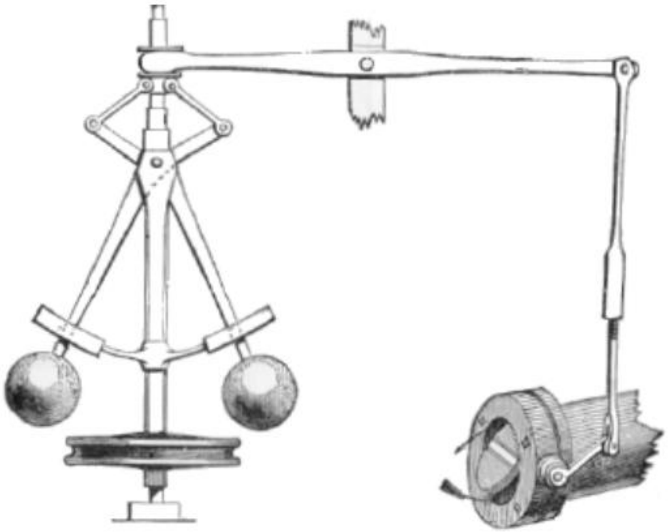


- Applications of automatic control include, but not limited to, aircraft, robots, civil engineering structures, process control,..., etc.
- Automatic control has played a vital role in the advance of engineering and science.

A VERY short control history

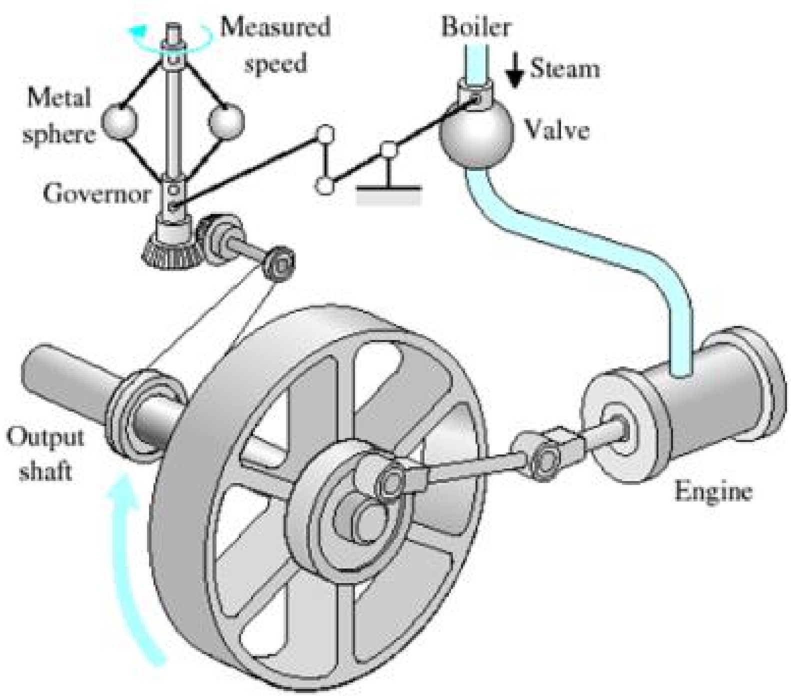
1. Kindergarten period

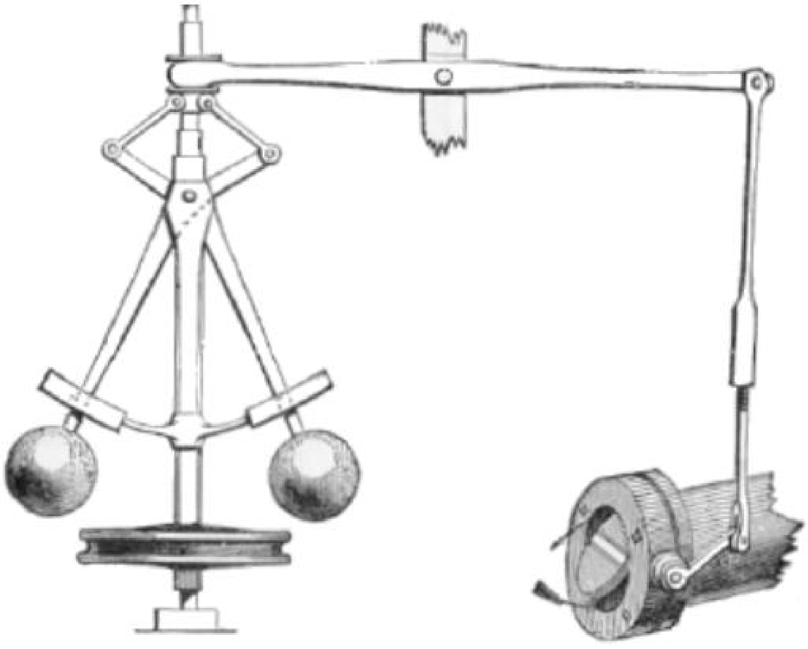
- Applied, but not aware or no theories appeared
- **Famous example**: A speed control system developed by James Watt in 1769, to maintain the rotating speed of a shaft in a steam engine



A VERY short control history

1. Kindergarten period





Watt’s Flyball Governor

A VERY short control history

2. Period in Classical control theories

- Examples
  - In 1868, "On Regulators", differential equation description
  - In 1877, Routh's Stability Criterion
  - In 1892, Lyaounov Stability
  - In 1932, Nyquist Stability Criterion
  - In 1938, Frequency response method
  - In 1948, Root Locus method
- Based on Laplace Transforms and Transfer function in Frequency domain
- Mainly on SISO Linear Constant Systems

A VERY short control history

3. Period in Modern control theories

- Branches
  - Linear system theories
  - Adaptive control
  - Optimal control
  - Predictive control
  - Discrete Event Dynamic System (DEDS)
  - H-infinite theories
- Based on State Space in Time domain
- On MIMO Nonlinear Time-variable Systems

A VERY short control history

4. Period in Intelligent control theories

- Branches
  - Neural network control
  - Fuzzy control
  - Genetic algorithm
  - Iterative learning control
  - Adaptive inverse control
  - Guidance, Navigation & Control (GNC) integrity system
- Based on diverse mathematical foundations
- Imitate methodologies of human or other animals

A VERY short control history

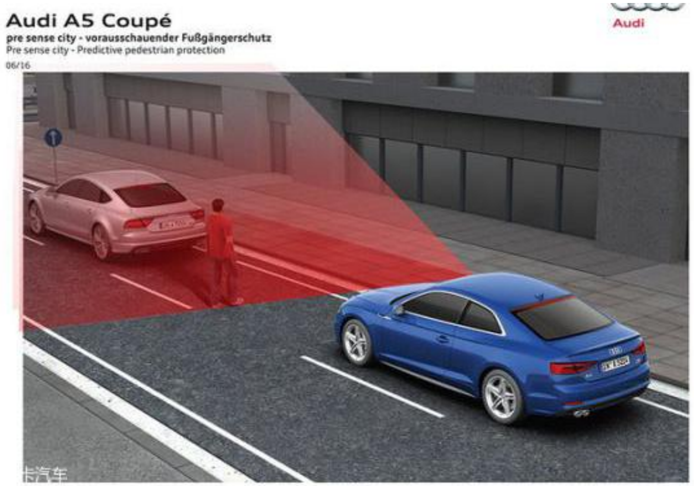
Current situation and perspectives

A VERY short control history

Current situation and perspectives

A VERY short control history

Current situation and perspectives



A VERY short control history

Other areas of interest:

- Biomedical devices
- Biological systems
- Environment
- Socio-Economic systems
- Financial markets
- Management
- ……

Why to study “Automatic Control” ?

- why do we need automatic control?

  \- Convenient (room temperature, laundry machine)

Why to study "Automatic Control" ?

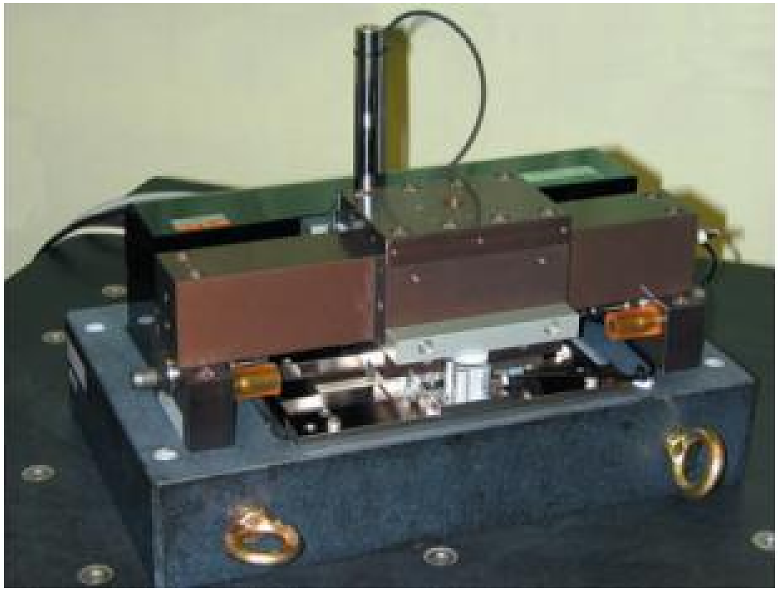
- why do we need automatic control?

  - Dangerous (hot/cold places, space, bomb removal)

Why to study “Automatic Control” ?

- why do we need automatic control?

  - Impossible for human (nanometer scale precision positioning, work inside the small space that human cannot enter, huge antennas control, elevator)



Why to study “Automatic Control” ?

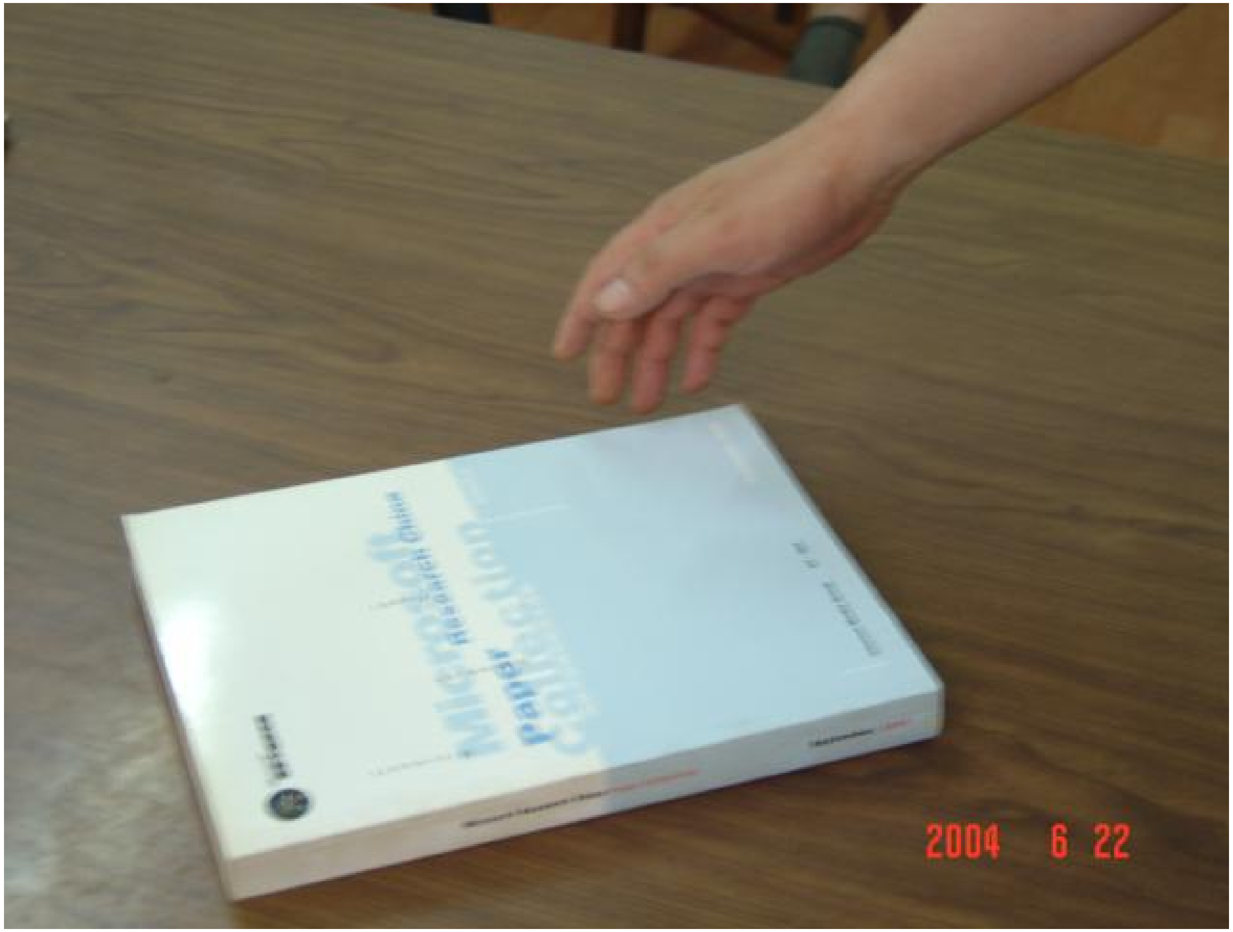
- why do we need automatic control?
  - High effeciency (engine control)

High temperature spot in the different zones of a car

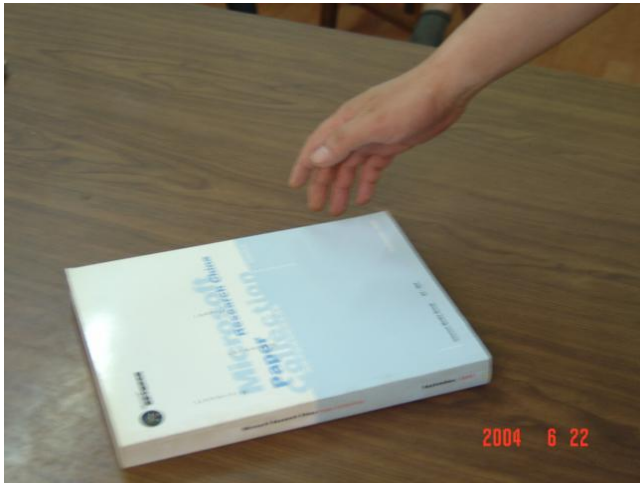
- Many examples of automatic control around us

What is “Automatic Control” ?

Example 1: manual control



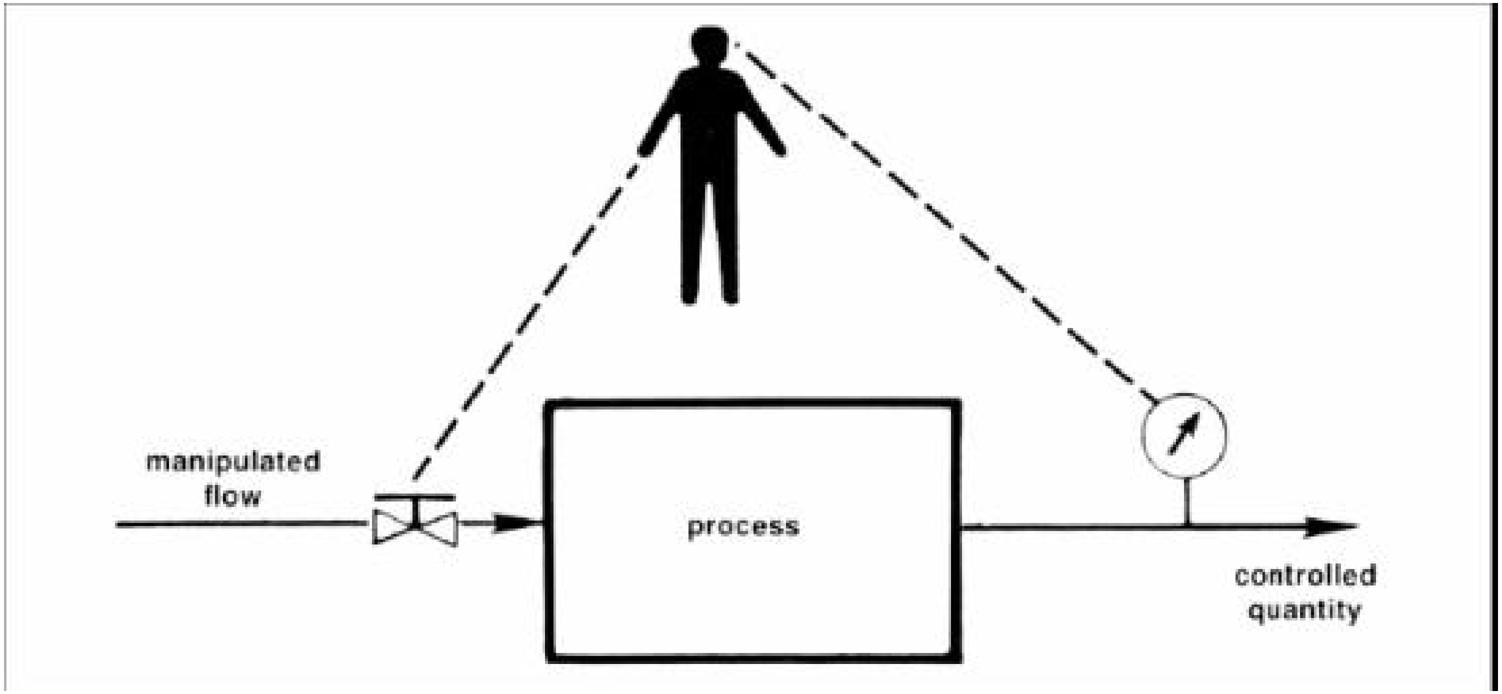
What is “Automatic Control” ?



- Objective: To pick up book by hands
- Outputs: Actual position of hands
- Inputs: Actual position of book
- Plants: hands / Arms / Legs

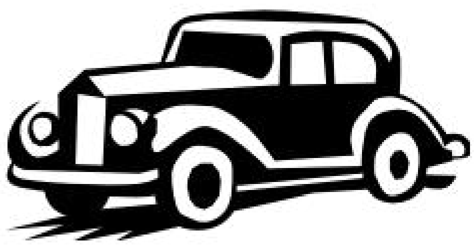
What is “Automatic Control” ?

Typical manual control



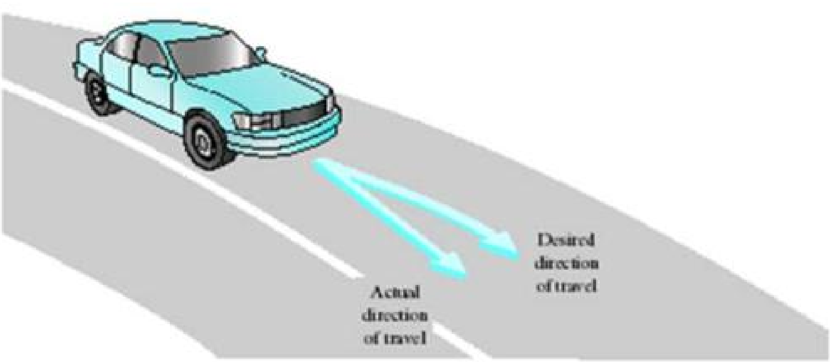
What is “Automatic Control” ?

- Example 2: driving a car implies controlling the vehicle to follow the desired path and arrive safely at a planned destination.



- If you drive the car yourself, you are performing a manual control of the car. If you design a machine to do it then you build an automatic control system.

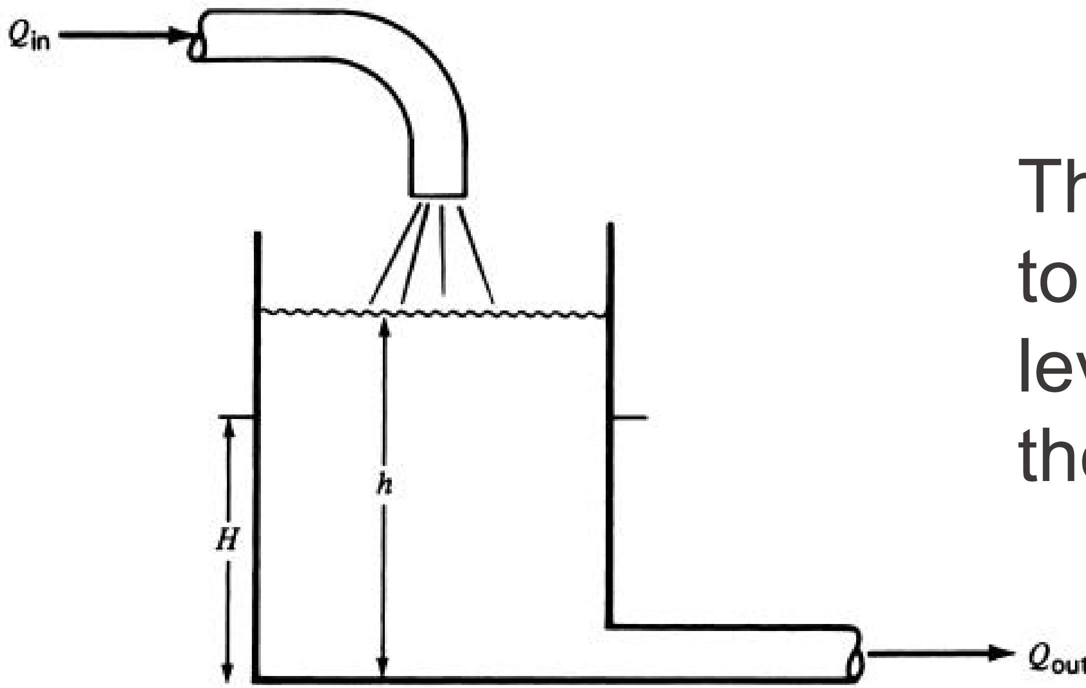
What is “Automatic Control” ?



- **Objective:** To control direction and speed of car
- **Outputs:** Actual direction and speed of car
- **Inputs:** Desired actual direction and speed of car
- **Disturbances:** Road surface and obstacles
- **Plants:** Car

What is “Automatic Control” ?

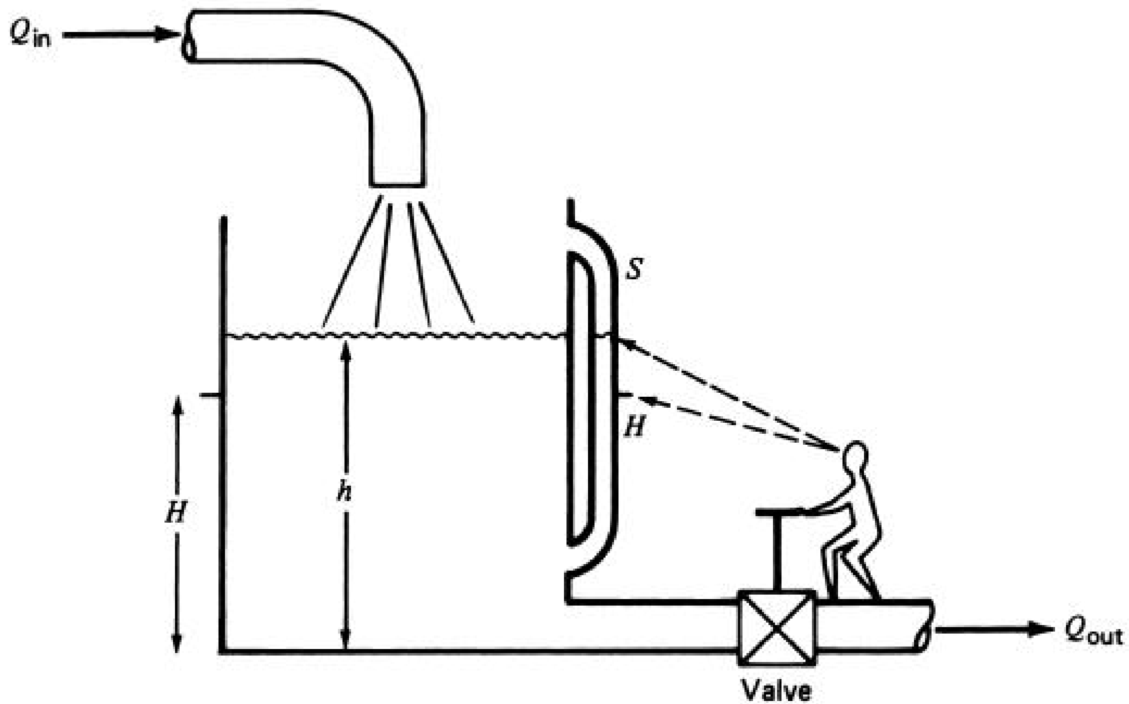
Example 3: Water level control



The objective is to regulate the level of water in the tank

What is "Automatic Control" ?

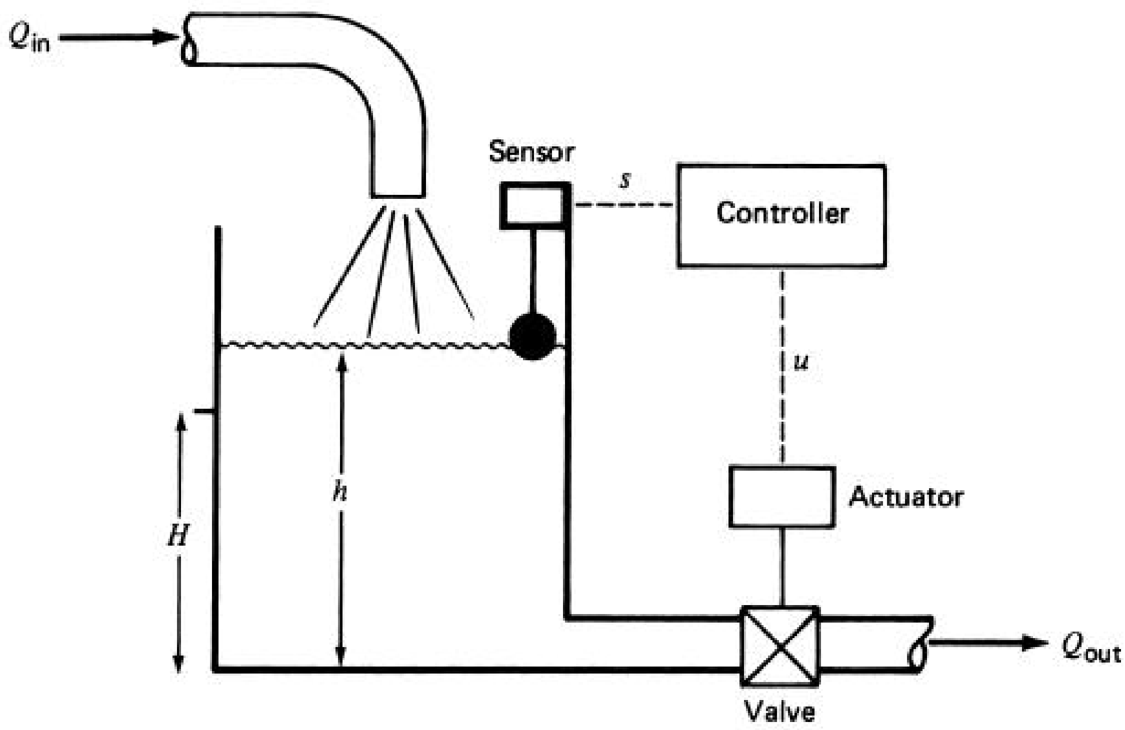
Example 3: Water level control - Manual control



A human can regulate the level using a sight tube, *S*, to compare the level, *h*, to the objective, *H*, and adjust a valve to change the level.

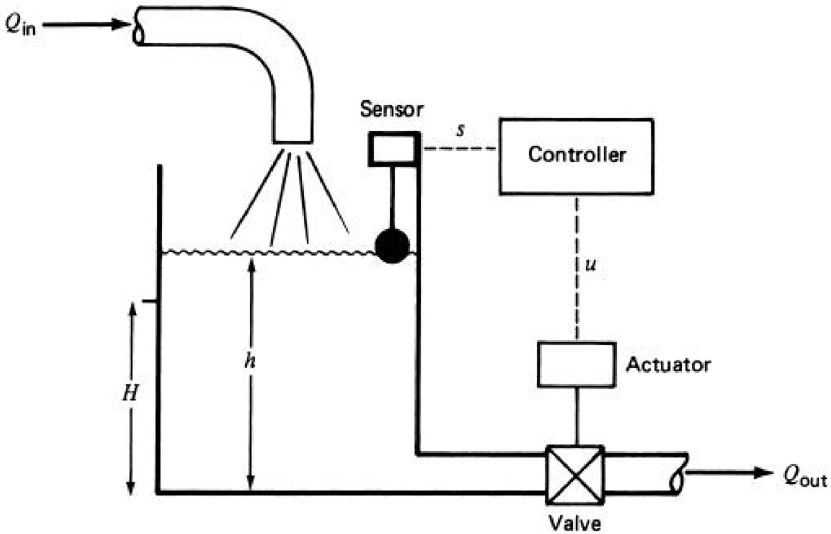
What is "Automatic Control" ?

Example 3: Water level control - Automatic control



An automatic level-control system replaces the human with a controller and uses a sensor to measure the level.

What is “Automatic Control” ?



- **Objective:** Level of water in the bank
- **Outputs:** Actual water level or height
- **Inputs:** Desired water level
- **Plants:** Tank

What is “Automatic Control” ?

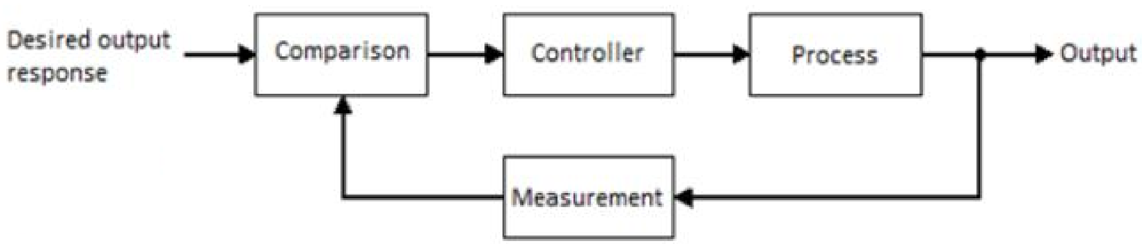
Water level manual control	Water level automatic control
Sense organ: Eye	Measurement instrument: Sensor
Central decision organ: Brain	Decision-making instrument: Controller
Effector organ: Hand	Actuator: Valve

- Not manual!

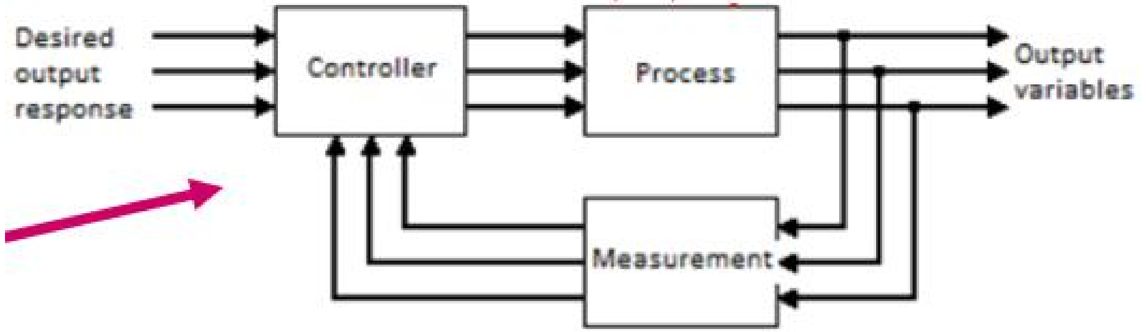
definitions

Process to be controlled

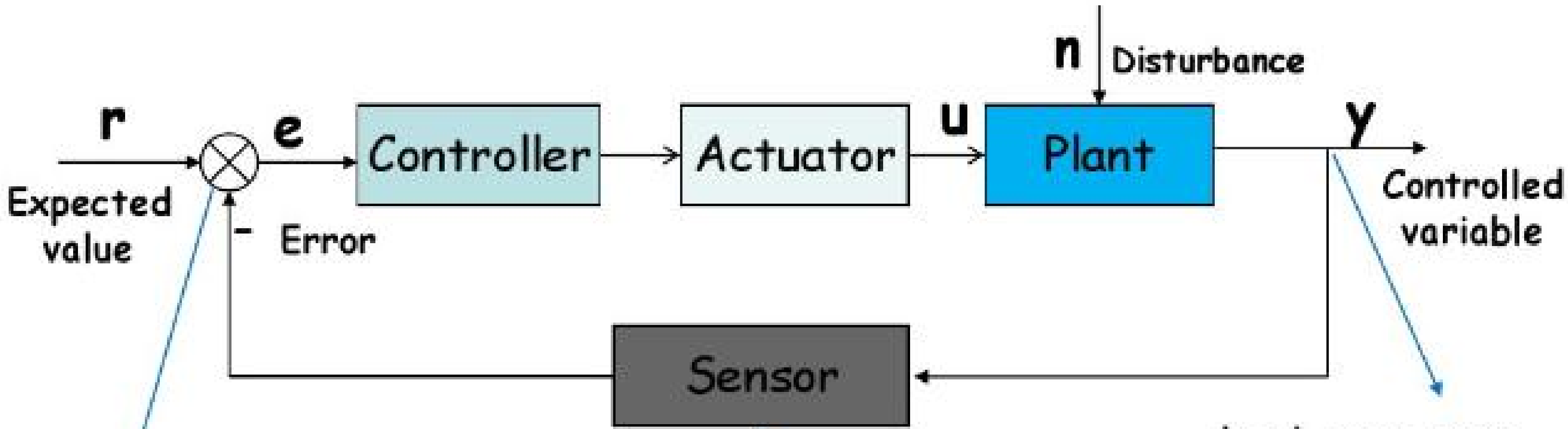
- SISO (single–input single–output) Control System



- MIMO (multi-input multi output) Multivariable Control System
-



Block diagram of automatic control system



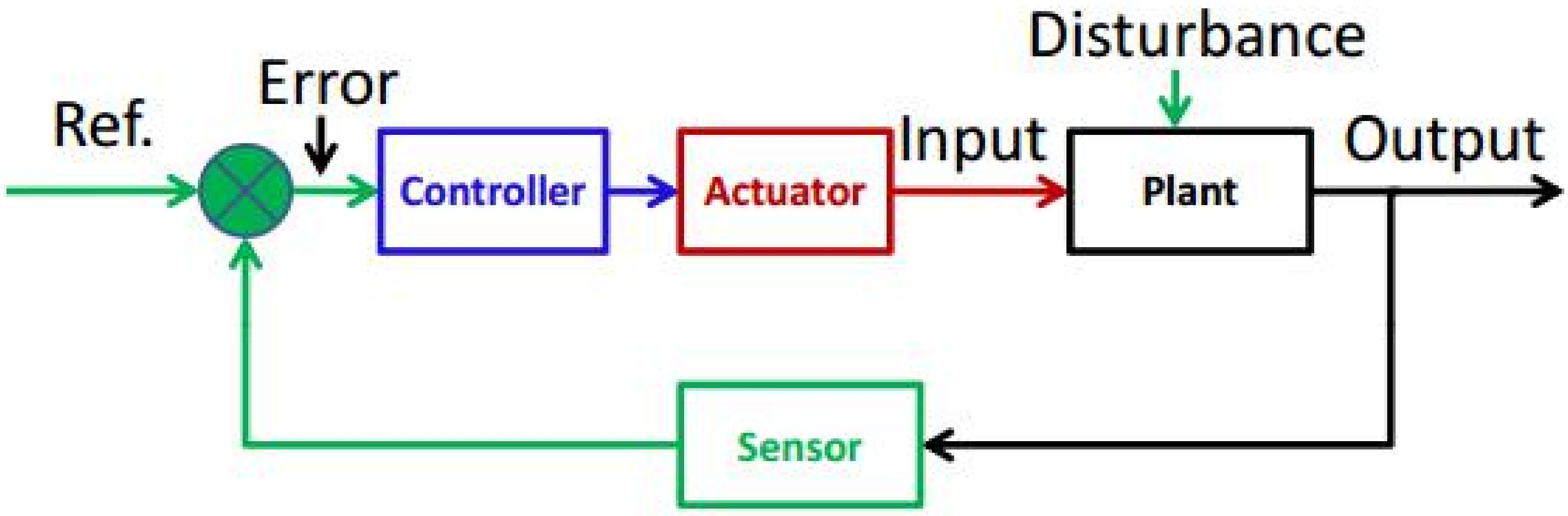
comparison component (comparison point) : its output equals the algebraic sum of all input signals.

"+": 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.

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

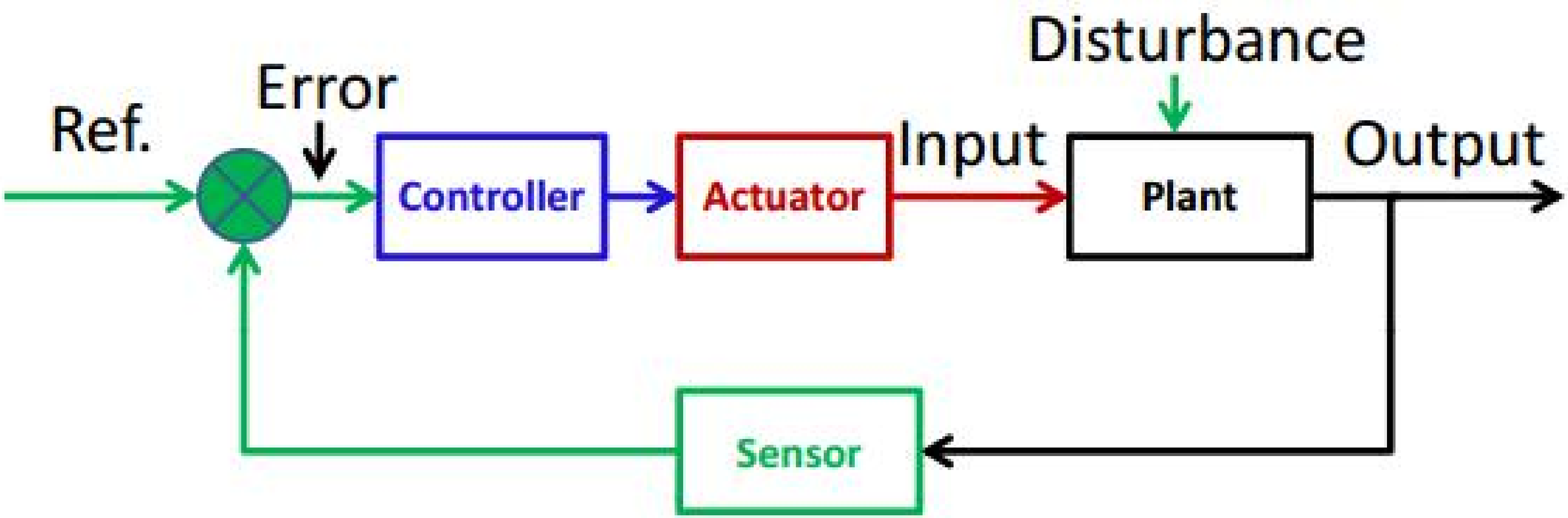
Basic elements of closed-loop system



Sensor

- Measures the output or controlled variable and provide the signal fed back to the comparison element

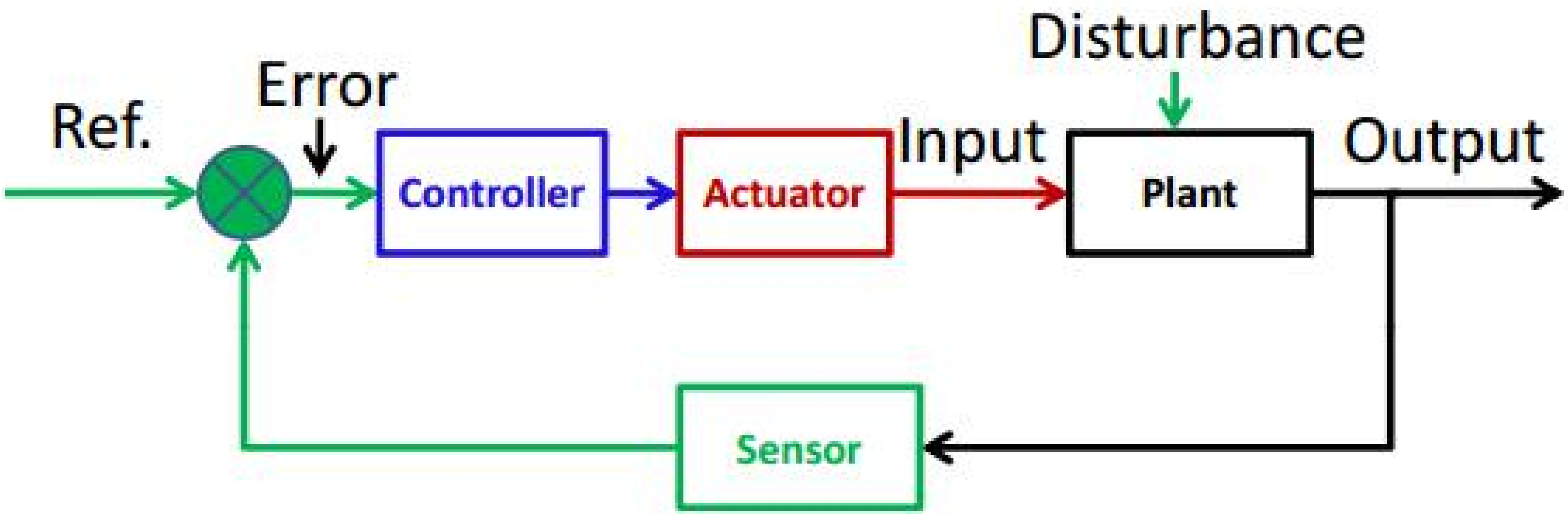
Basic elements of closed-loop system



Controller Make the output following the reference in a "satisfactory" manner even under disturbances

Actuator Acts on the plant directly to adjust controlled variables

Basic elements of closed-loop system



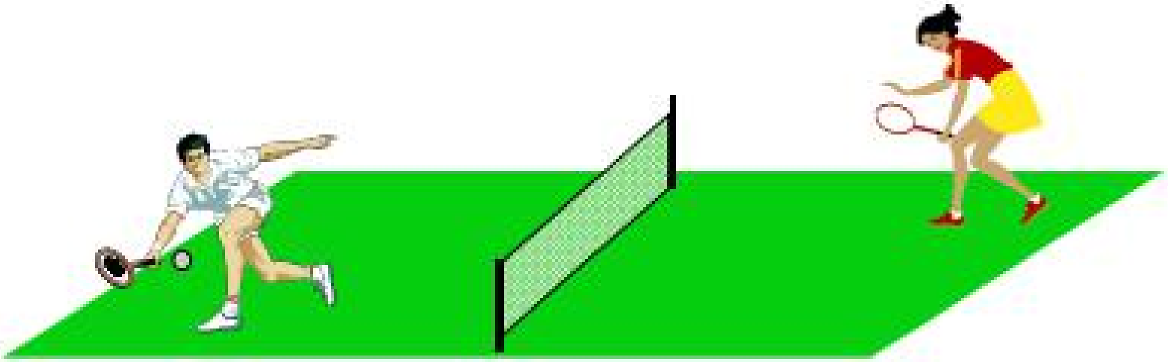
Process / Plant

- Physical object or system to be controlled

Basic elements of closed-loop system

Better Sensors
Provide better *Vision*

Better Actuators
Provide more *Muscle*

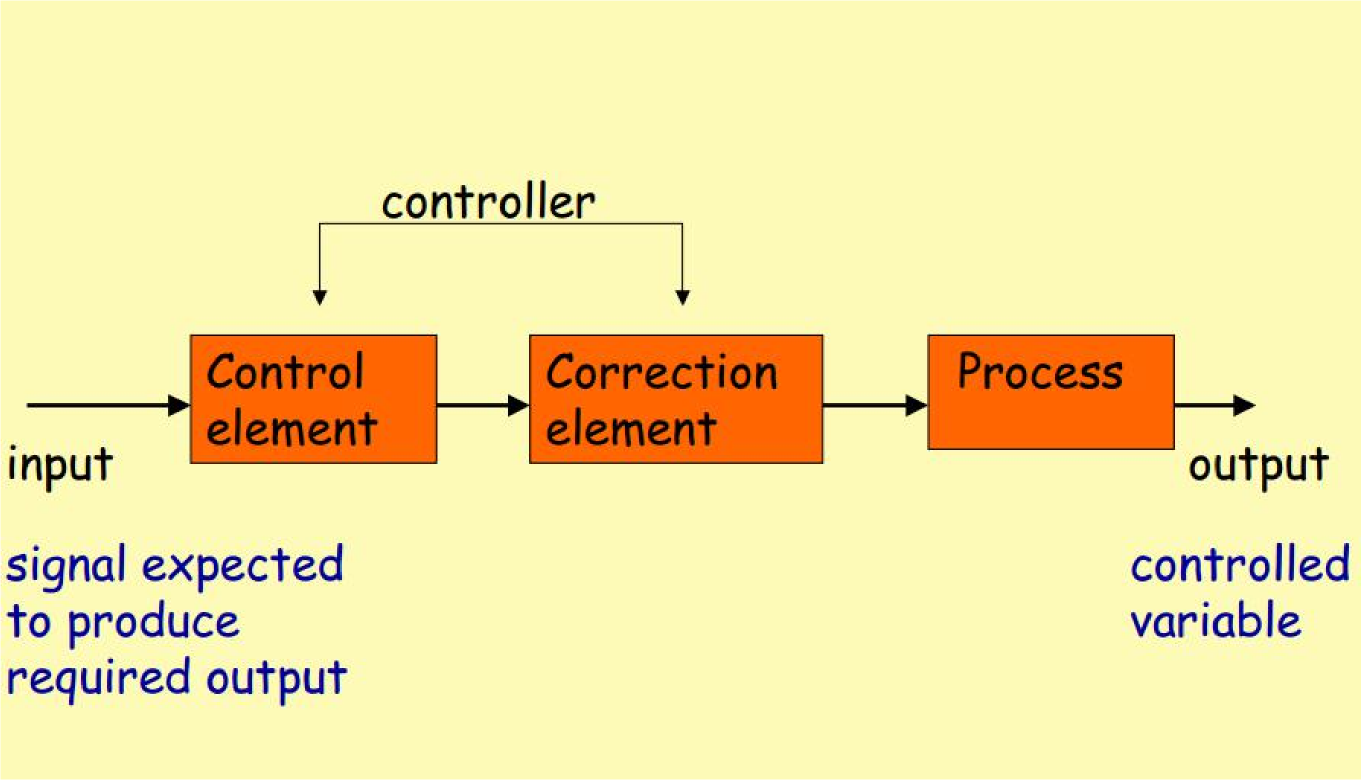


Better Control Provides more finesse by combining *sensors* and *actuators* in more intelligent ways

definitions

- Open-Loop Control Systems

Utilize a controller or control actuator to obtain the desired response.



Open Loop vs. Closed Loop

Example 5: Open-loop Control

A laundry machine washes clothes, by setting a program. It does not measure how clean the clothes become.

Open Loop vs. Closed Loop

Example 5: Open-loop Control – Laundry Machine

Program setting (Input) → Laundry Machine → Washed clothes (Output)

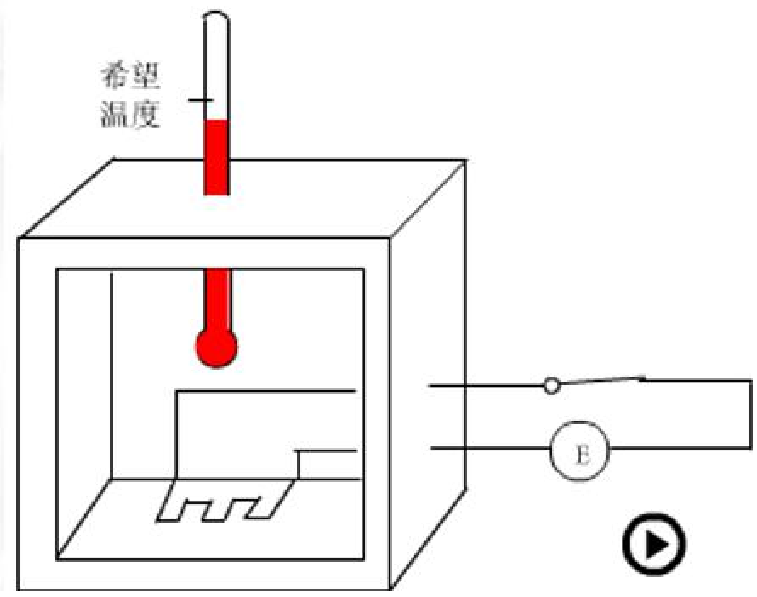
Open Loop vs. Closed Loop

Example 6: Open-loop Control

Input: Desired room temperature

Output: Actual room temperature

Plants: heating furnace

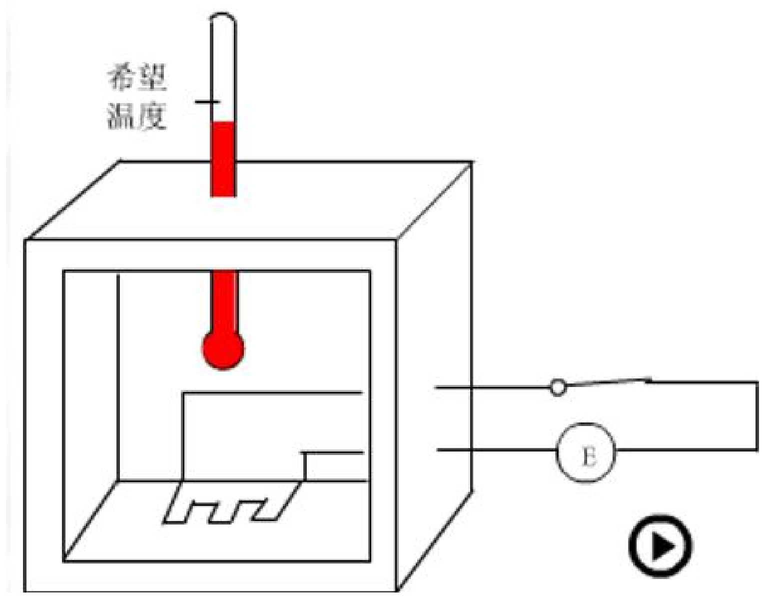


Home heating control system

Open Loop vs. Closed Loop

Example 6: Open-loop Control

If the temperature of furnace is not satisfactory, it **cannot** automatically alter the time.

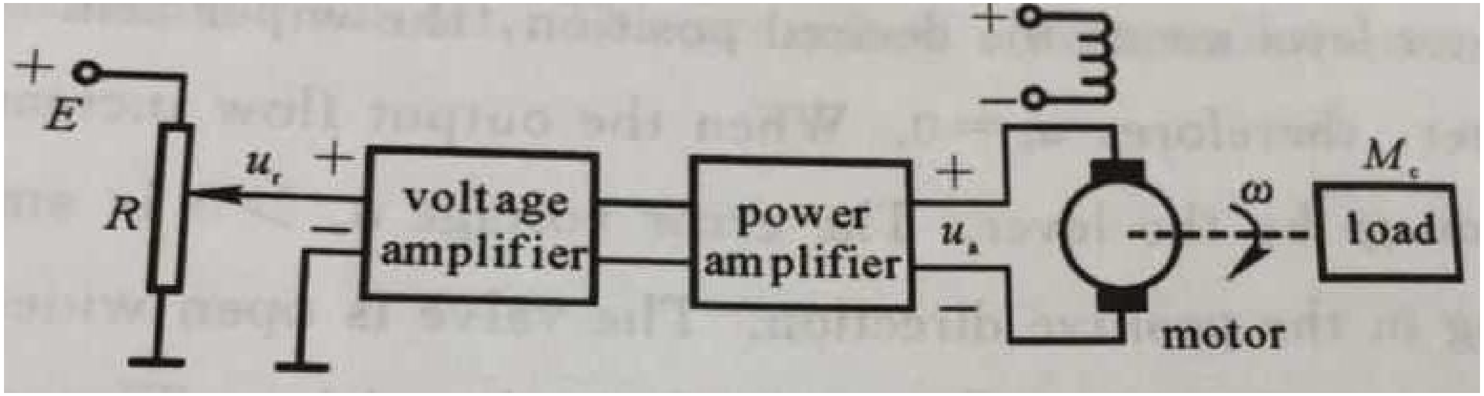


Desired temperature (Input) → **Heating furnace** → Temperature (Output)

Open Loop vs. Closed Loop

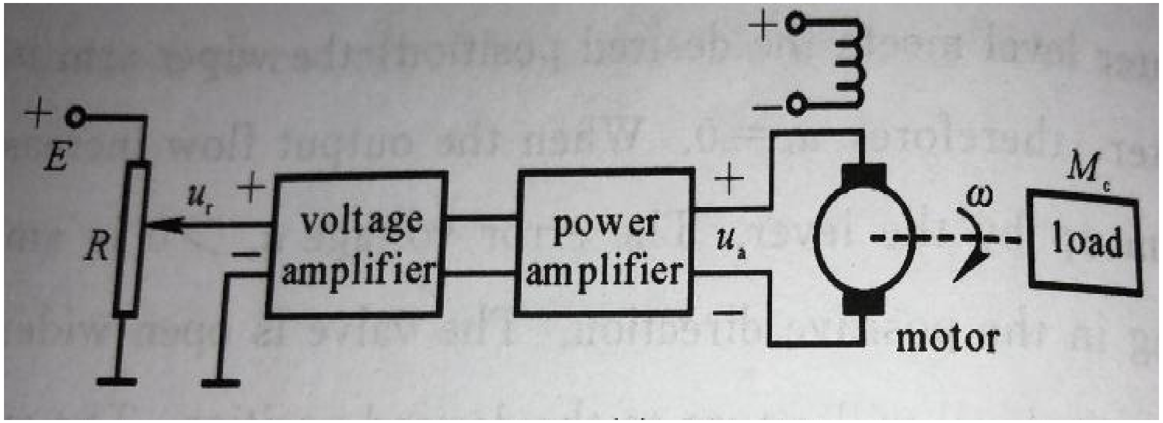
Example 6: Open-loop Control – DC motor

Input: reference voltage
Output: speed of the shaft
Plants: DC motor



Open Loop vs. Closed Loop

Example 6: Open-loop Control – DC motor

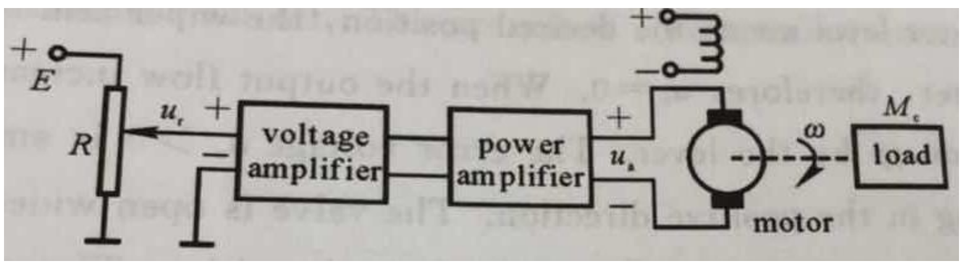


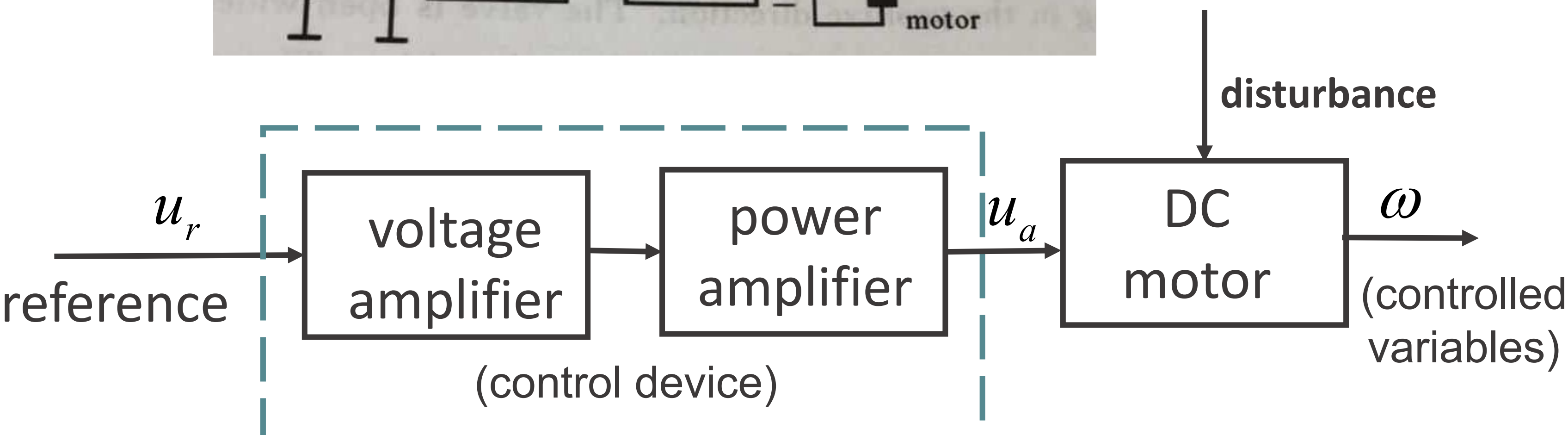
If a variation of the speed from the desired value appears, due to a change of mechanical load on the shaft, it is no way to change the value of input quantity automatically.

Open Loop vs. Closed Loop

Example 6: Open-loop Control – DC motor

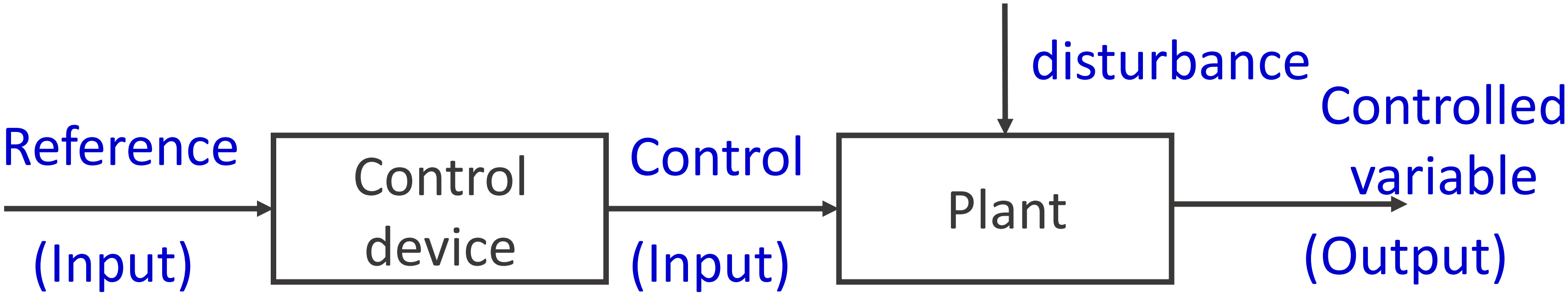
slide rheostat
(generates reference voltage) – – – – → speed
suppose 0 ~ 10V　　　　0 ~ 1000r





Open-loop control systems

Example 6: Open Loop Control – DC motor



Functional block diagram of a open-loop control system

- The output is not measured and compared with the input, no feedback
- Control without measuring devices (sensors) are called open-loop control
- The accuracy of the system depends on calibration
- In the presence of disturbance ?

Open-loop control systems

Advantages:

- Simple construction and ease of maintenance.
- Convenient when output is hard to measure or measuring the output precisely is economically not feasible. (e.g. washer system)

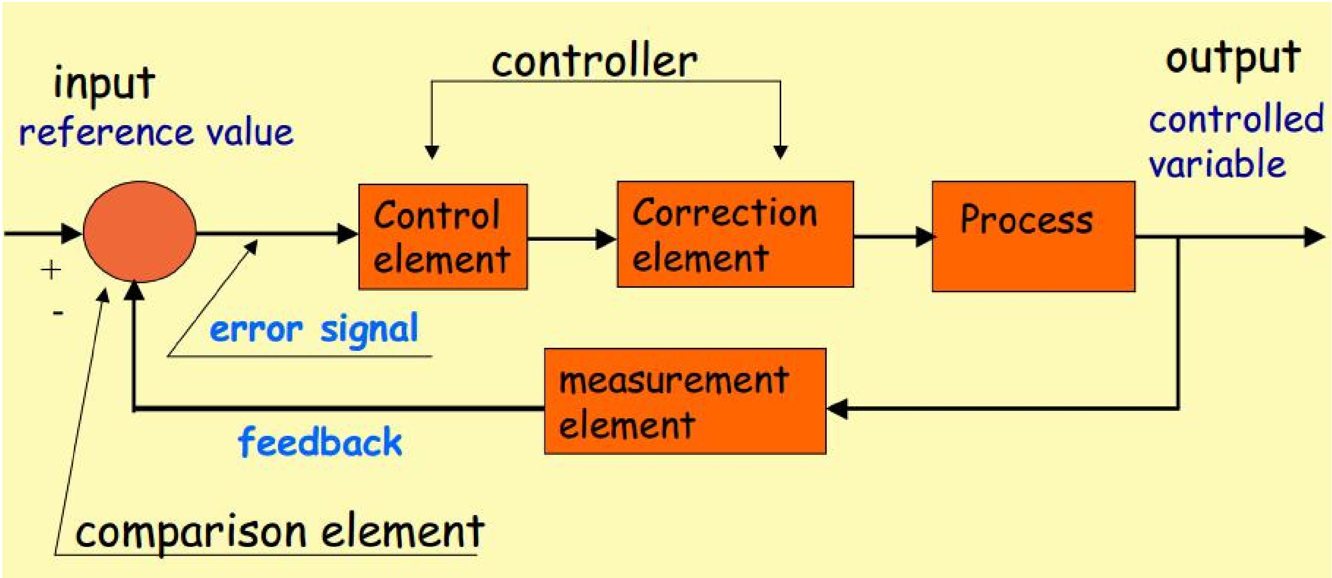
Disadvantages:

- Disturbances and changes in calibration cause errors, and the output may be different from what is desired.

Open Loop vs. Closed Loop

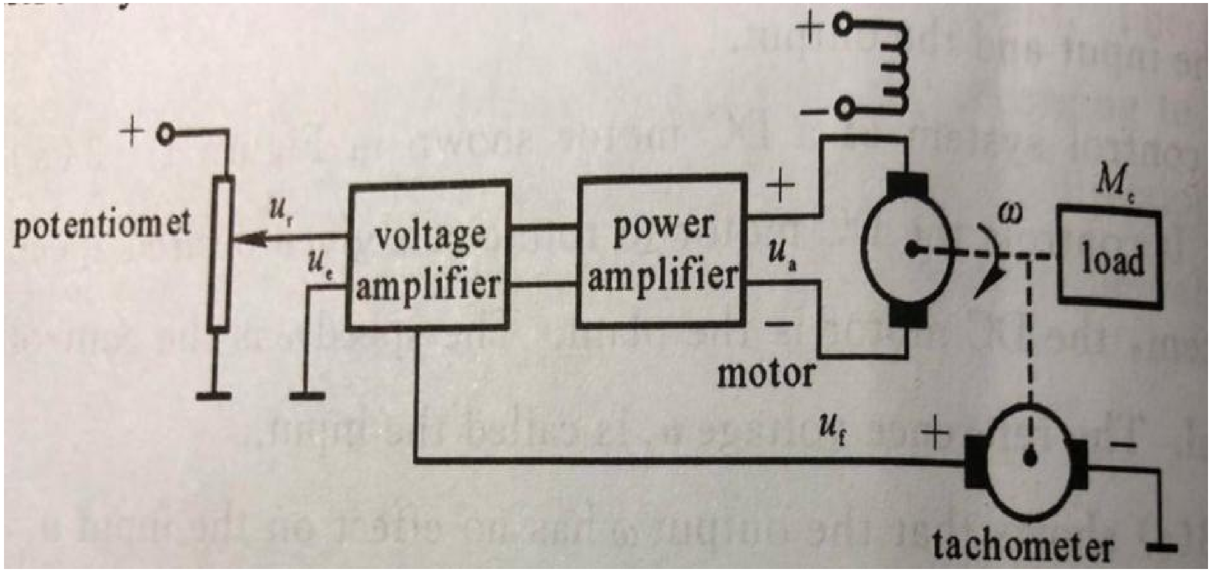
Closed-loop (feedback) control

- In this approach, the quantity to be controlled, say C, is measured, compared with the desired value, R, and the error between the two, $E = R - C$ used to adjust C. This means that the control action is somehow dependent on the output.



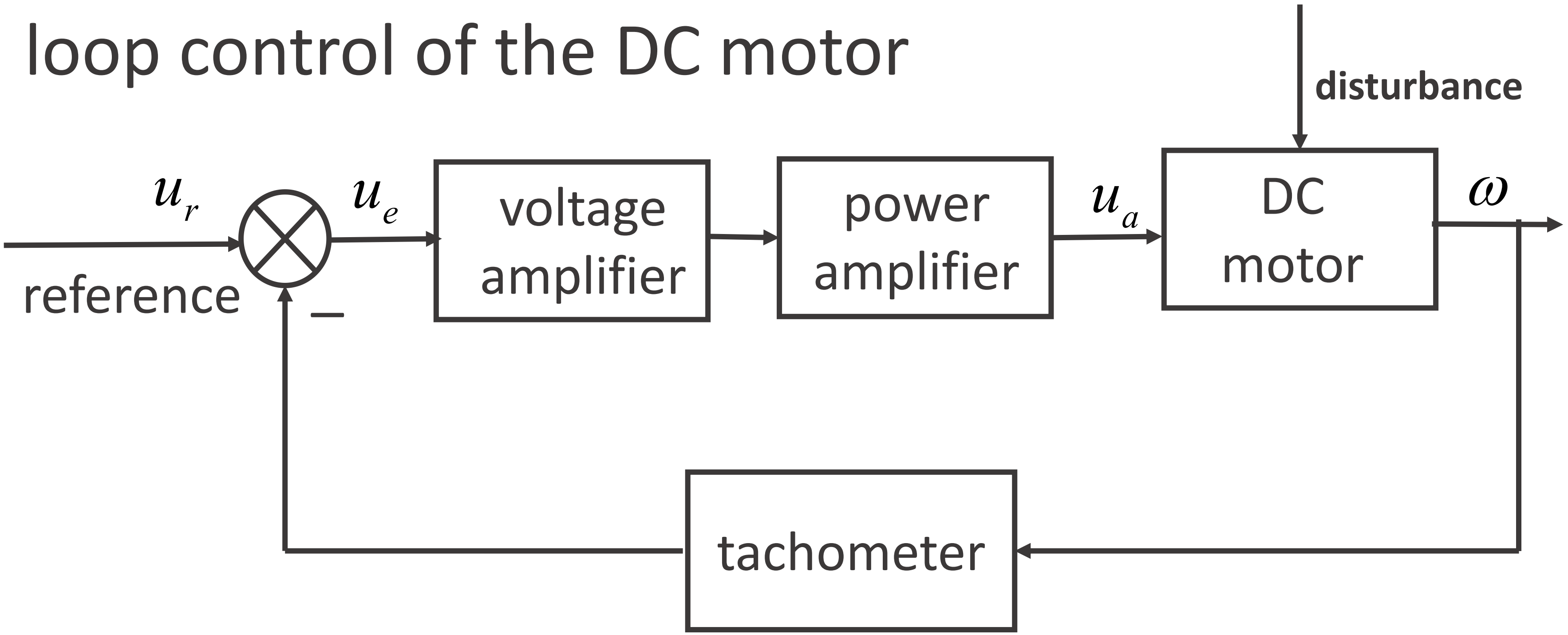
Closed Loop (feedback) control

Example 7: Closed-loop Control – Speed closed-loop control of the DC motor



Closed Loop (feedback) control

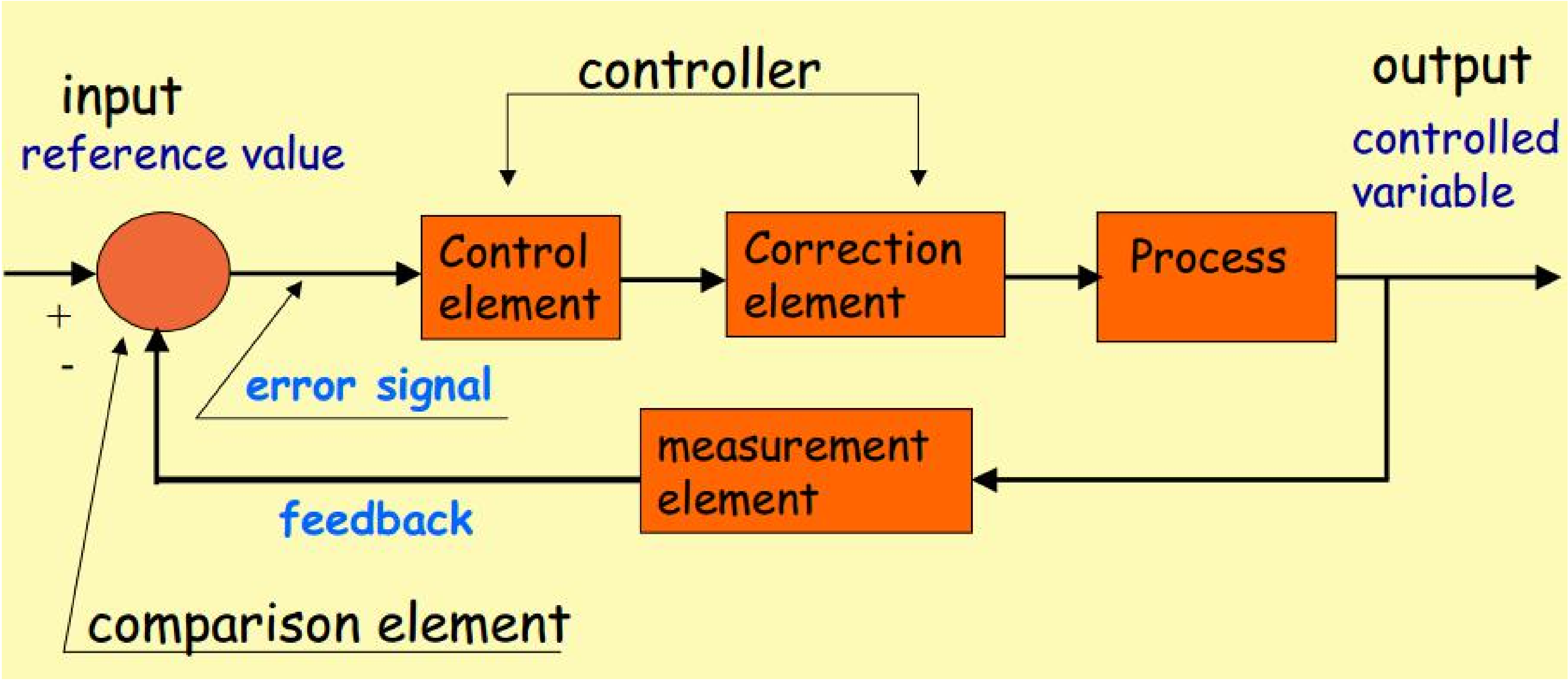
Example 7: Closed-loop Control – Speed closed-loop control of the DC motor



Its core idea: Negative feedback

Open Loop vs. Closed Loop

Closed-loop (feedback) control

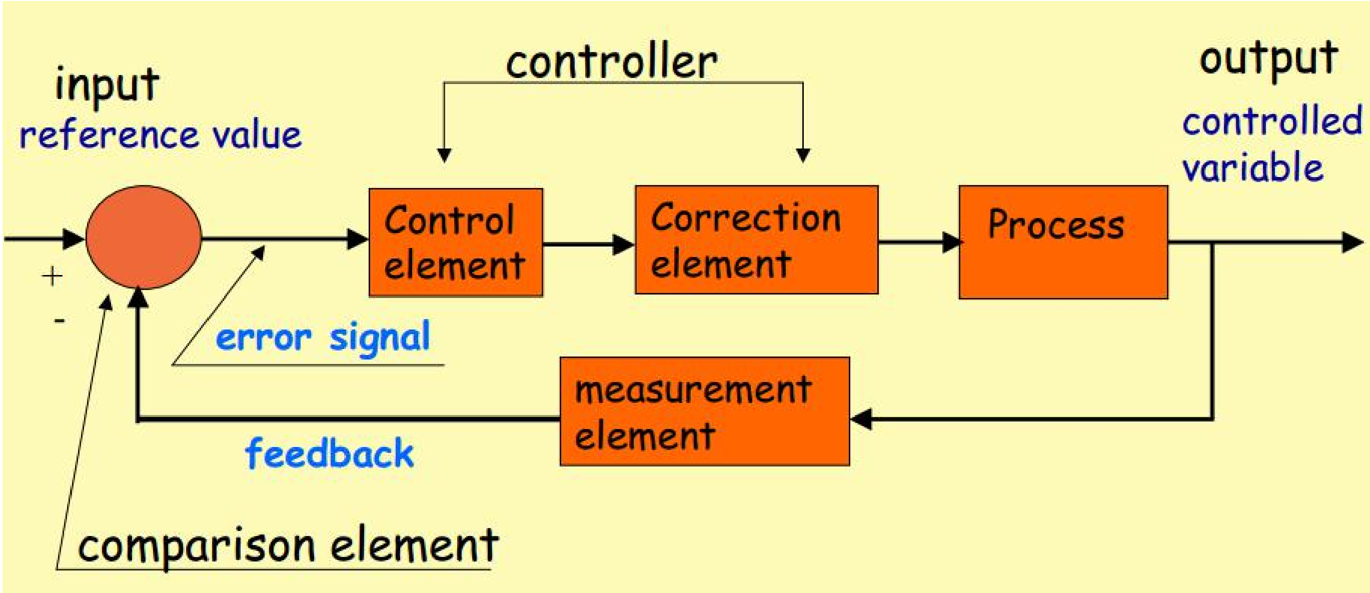


Generalized feedback control system

Open Loop vs. Closed Loop

Closed-loop (feedback) control

- The closed-loop control system implies that the action results from the comparison between the output and input quantities in order to maintain the output at the desired value



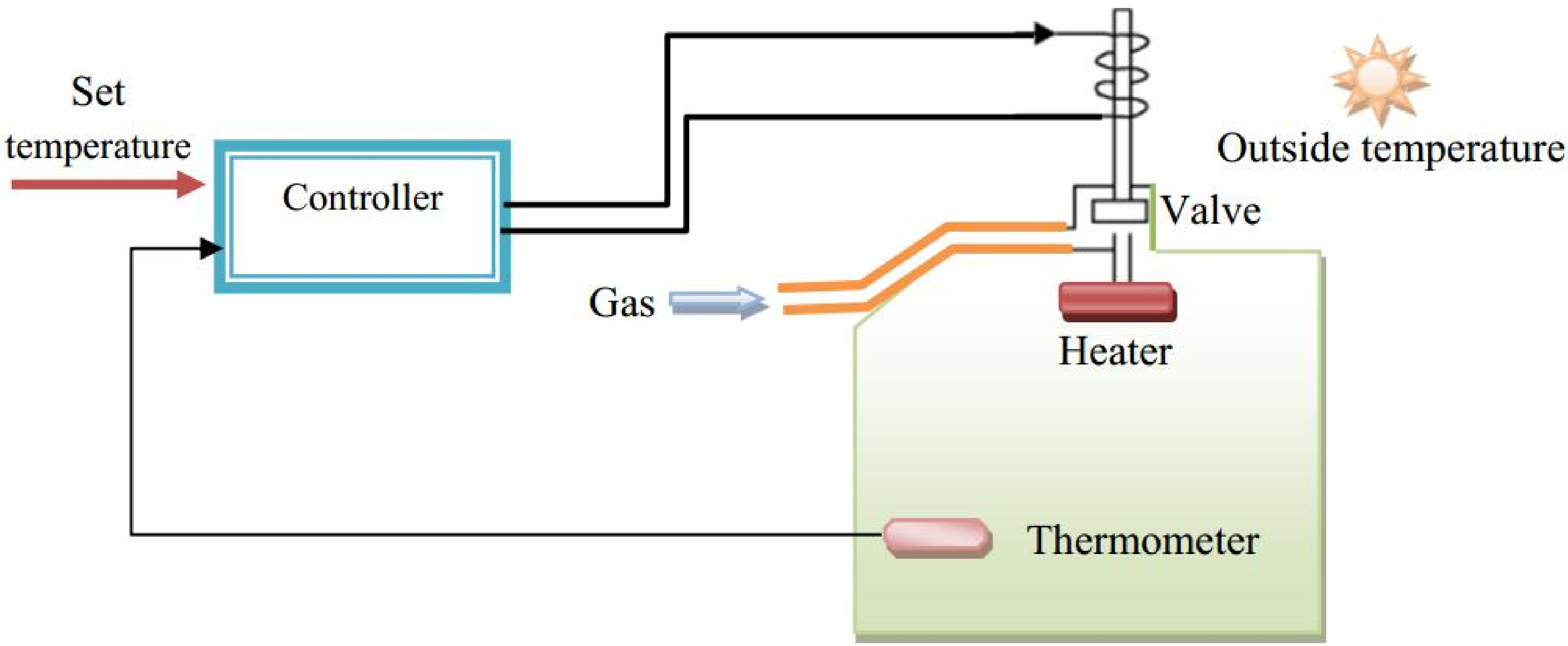
	Open-Loop System	Closed-Loop System
1. 2. 3. 4.	<u>Advantages</u> An easy system Inexpensive Usually this kind of system faces many instability problems Suitable for systems that involves output that is difficult to measure	<u>Advantages</u> Not sensitive towards external influences Has high levels of accuracy Able to reduce instability
 1. 2. 3.	<u>Disadvantages</u> Sensitive towards external influences Inability to influence instability Constant calibration of the controller is required to ensure the quality and accuracy of the system	<u>Disadvantages</u> System is usually complex The system can become unstable

Exercise

1. Consider an electric oven in a typical modern kitchen. Identify the objective, plant, controlled variable, and the disturbances.
2. Imagine you own a backyard swimming pool! Describe a manual control system to measure pH and to add an acidic solution to adjust pH. Define the plant, controlled variable, and the disturbances.
3. Now automate the control of your swimming pool! Assume you have a tank of acid solution to pump into your pool to control pH.

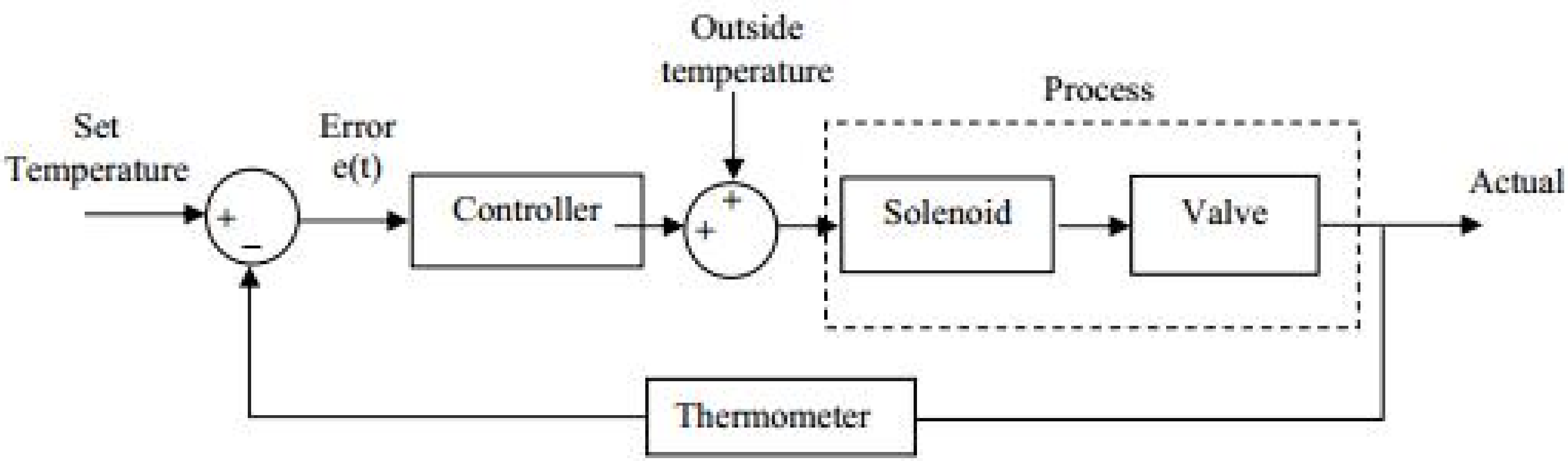
Open Loop vs. Closed Loop

Exercise: Closed-loop Control – Room temperature control system



Open Loop vs. Closed Loop

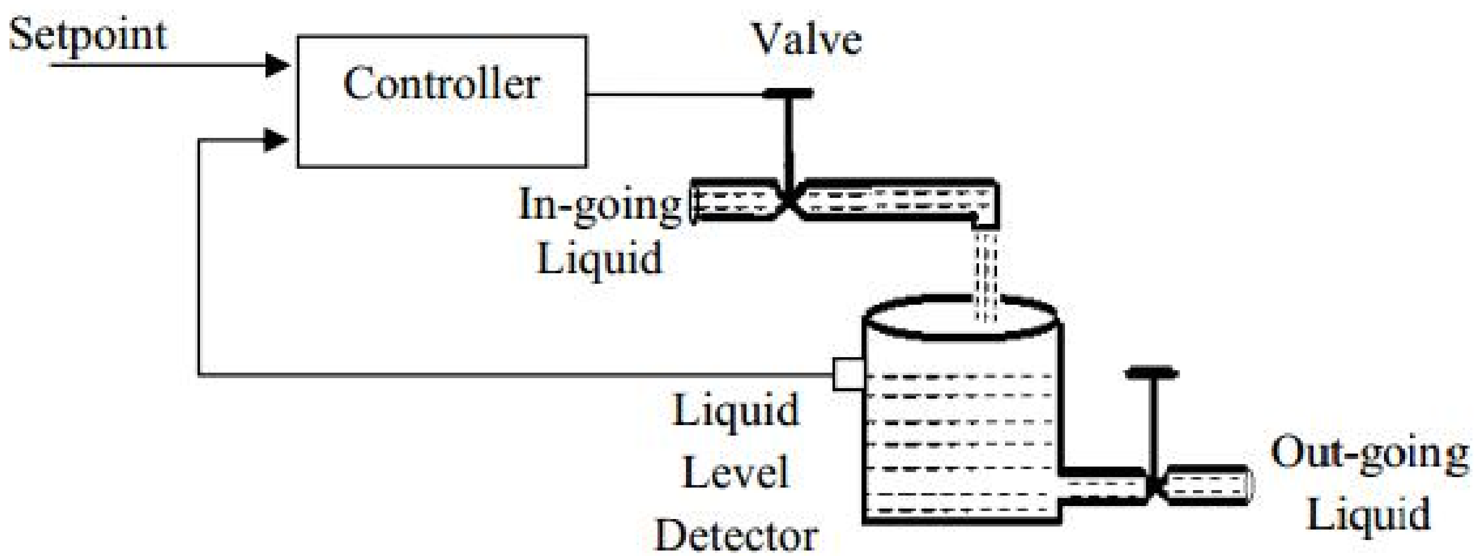
Exercise: Closed-loop Control – Room temperature control system



Closed Loop (feedback) control

Exercise: Liquid level control system-

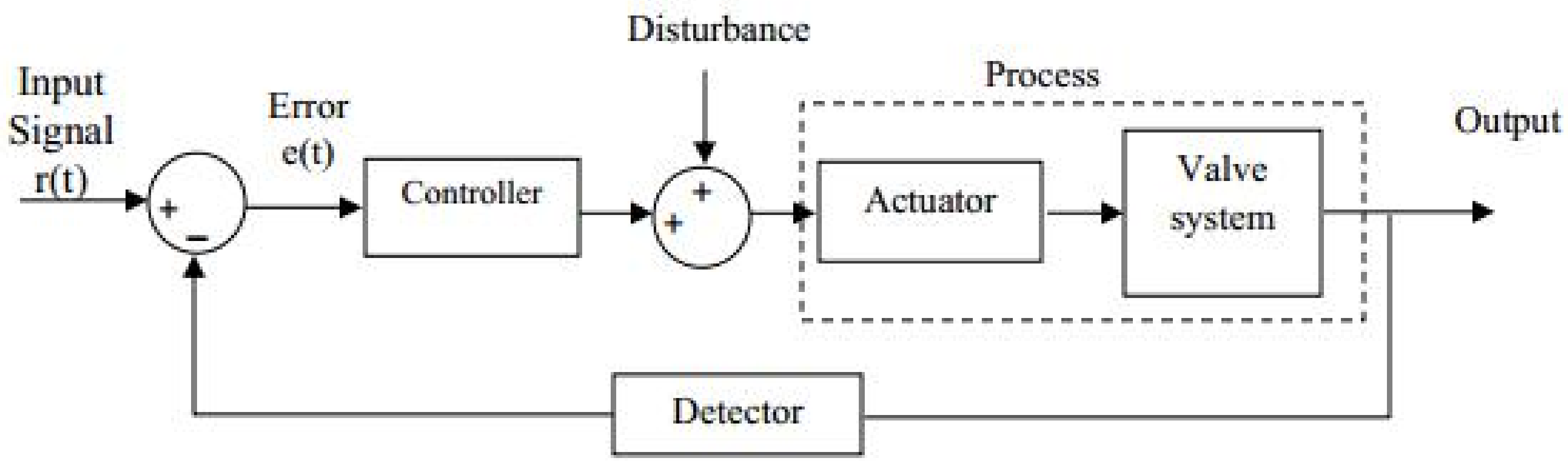
Block diagram



Closed Loop (feedback) control

Exercise: Liquid level control system-

Block diagram



Principles of Automatic Control

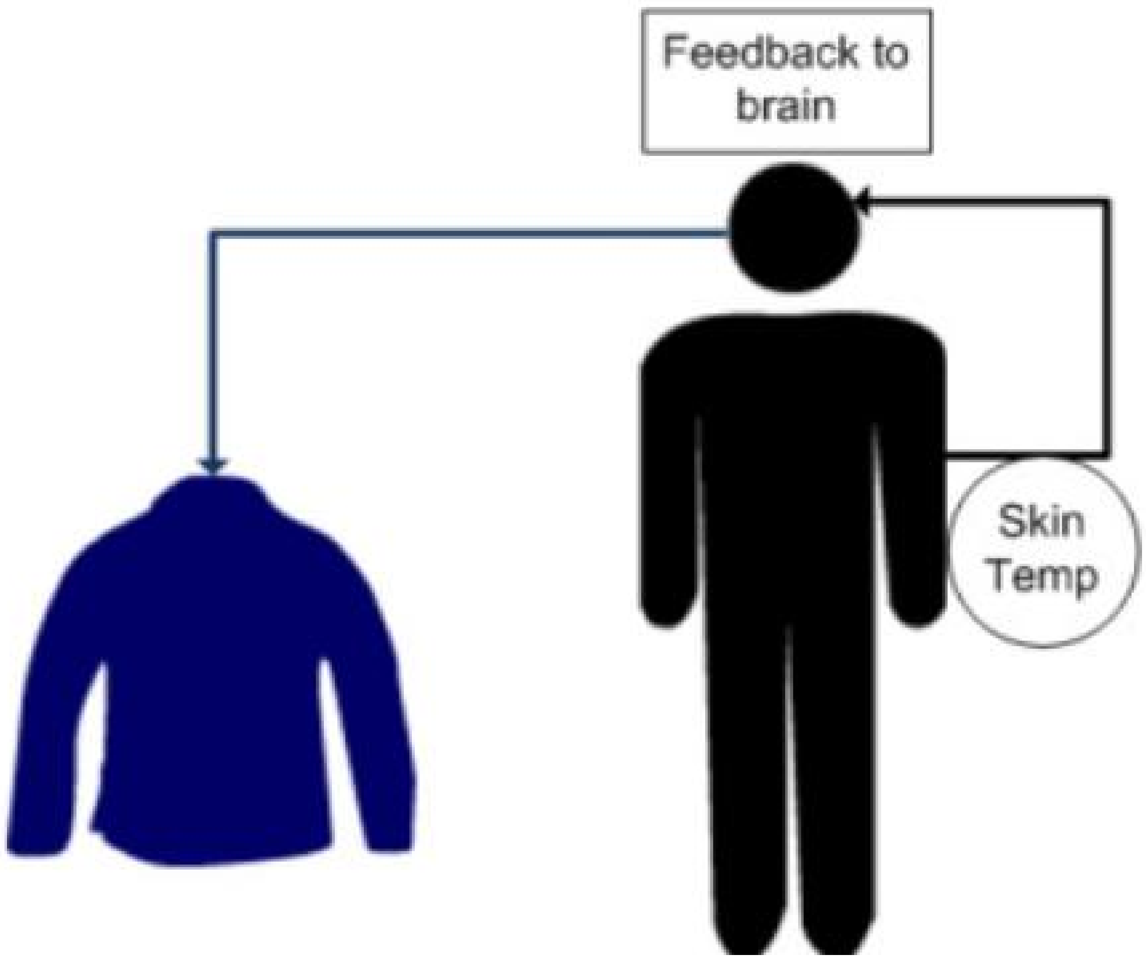
More examples of feedback control system

Feedback control systems exist everywhere

- E.g. the human body is highly advanced feedback control system.
- Body temperature and blood pressure are kept constant by means of physiological feedback.
- Feedback makes the human body relatively insensitive to external disturbance. Thus we can survive in a changing environment.

Feedback control systems exist everywhere

- E.g. Winter growing up in Kaifeng



Feedback control systems exist everywhere

- E.g. autopilot mechanism

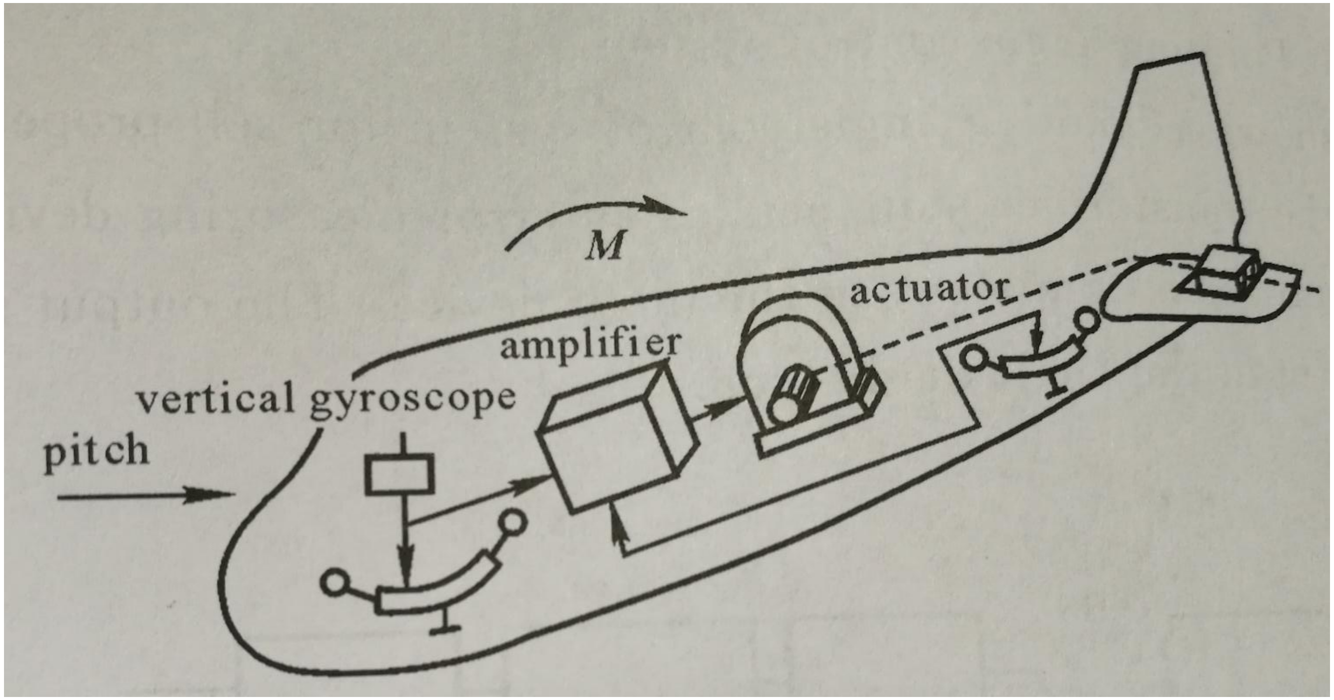
Feedback control systems exist everywhere

- E.g. autopilot mechanism

Its purpose is to maintain a specified airplane heading, despite atmospheric changes. It performs this task by continuously measuring the actual airplane heading, and automatically adjusting the airplane control surfaces (rudder, ailerons, etc.) so as to bring the actual airplane heading into correspondence with the specified heading.

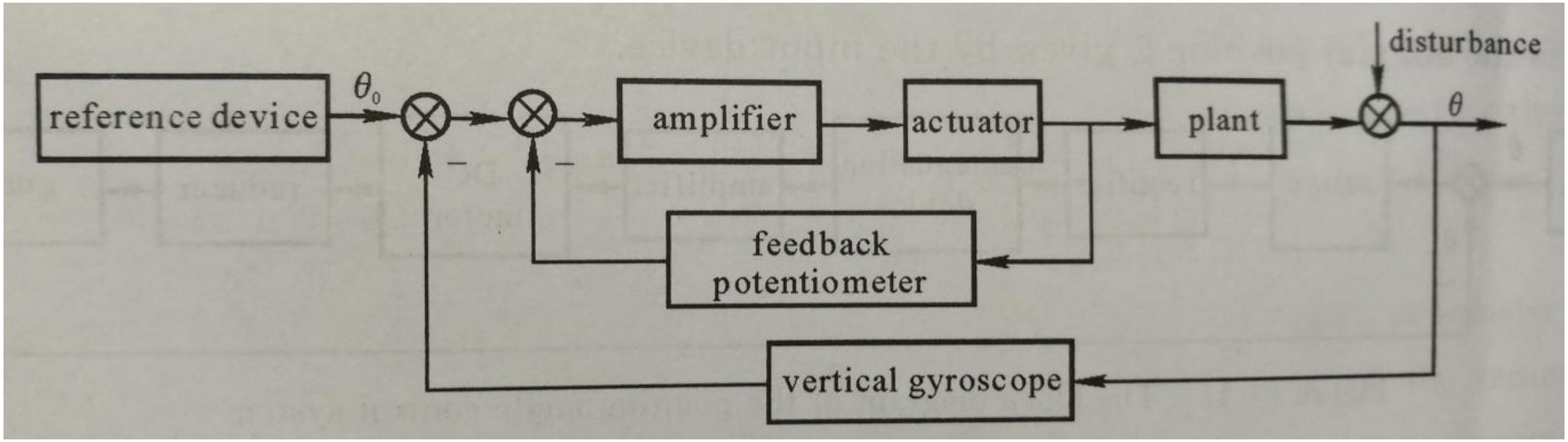
Feedback control systems exist everywhere

- E.g. autopilot mechanism



Feedback control systems exist everywhere

- E.g. autopilot mechanism



Feedback control systems exist everywhere

- E.g. Plotter

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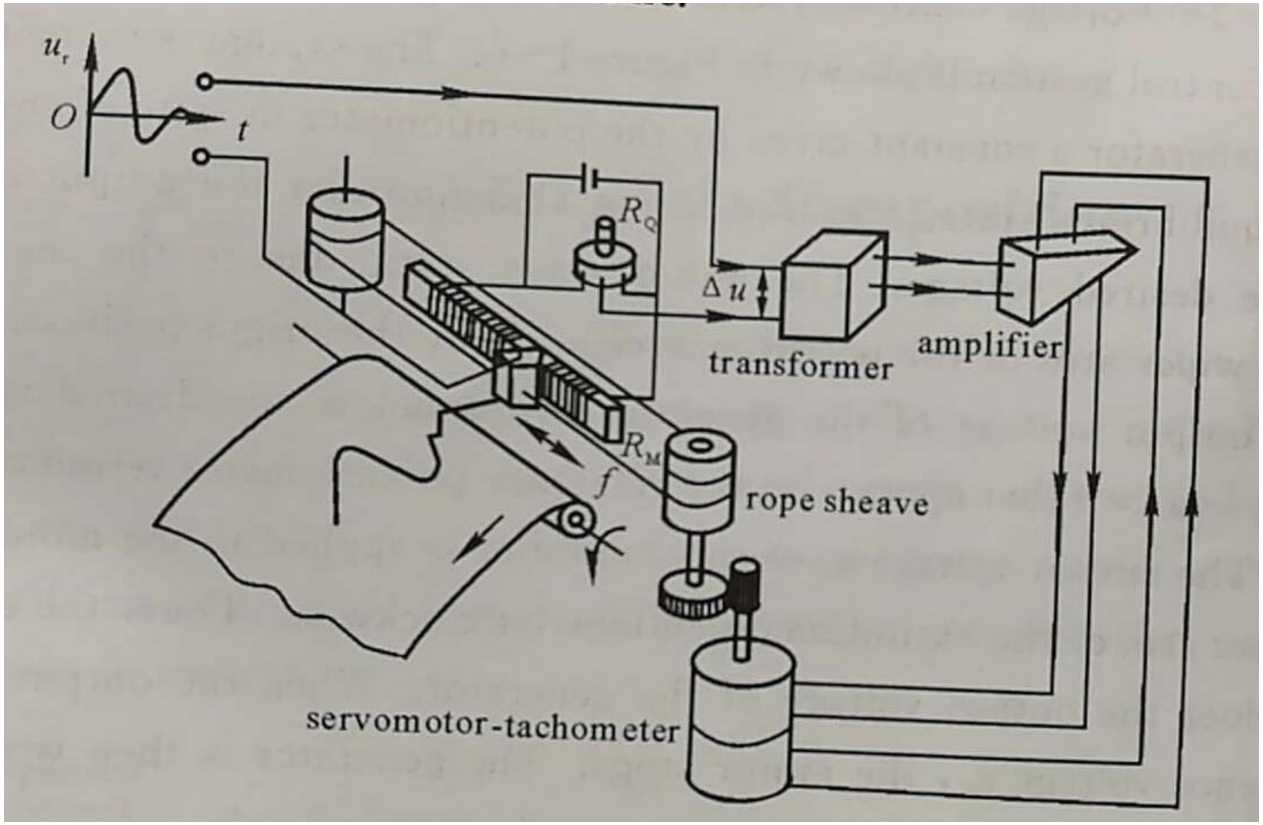
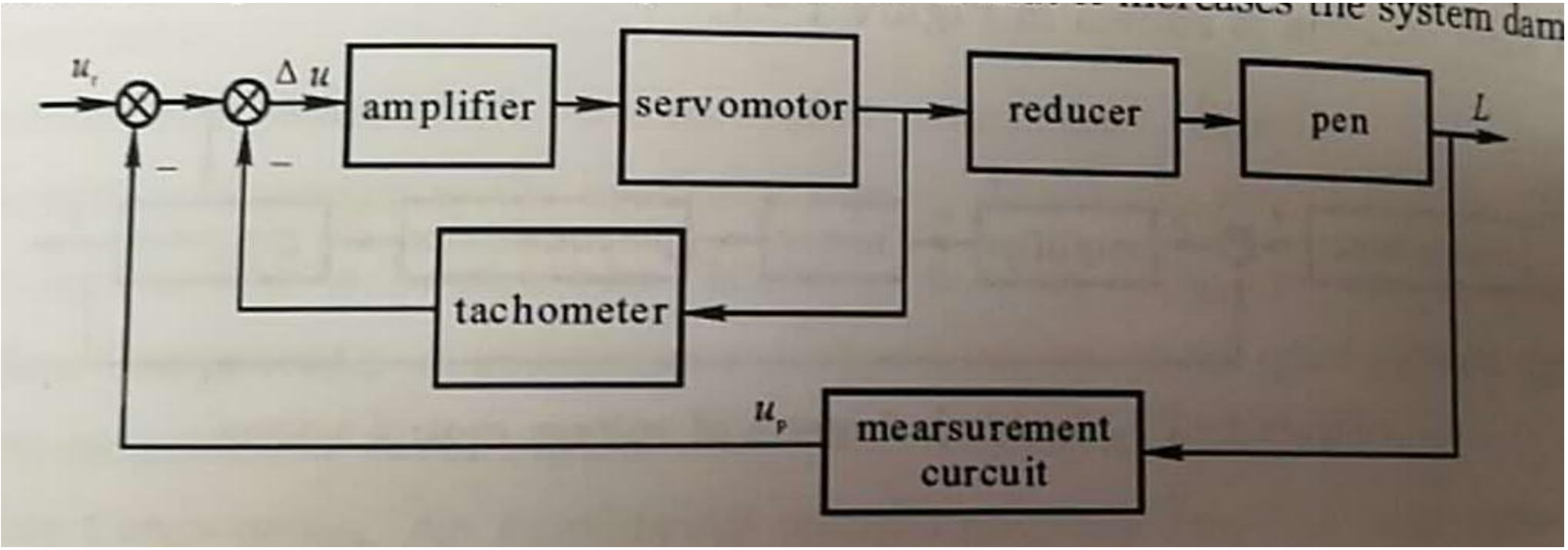


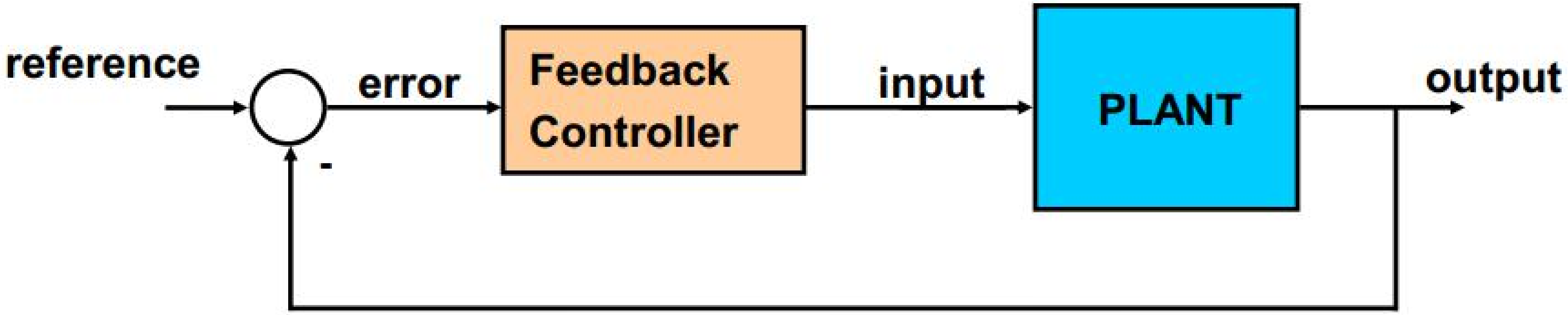
Feedback control systems exist everywhere

- E.g. Plotter



Composite control system

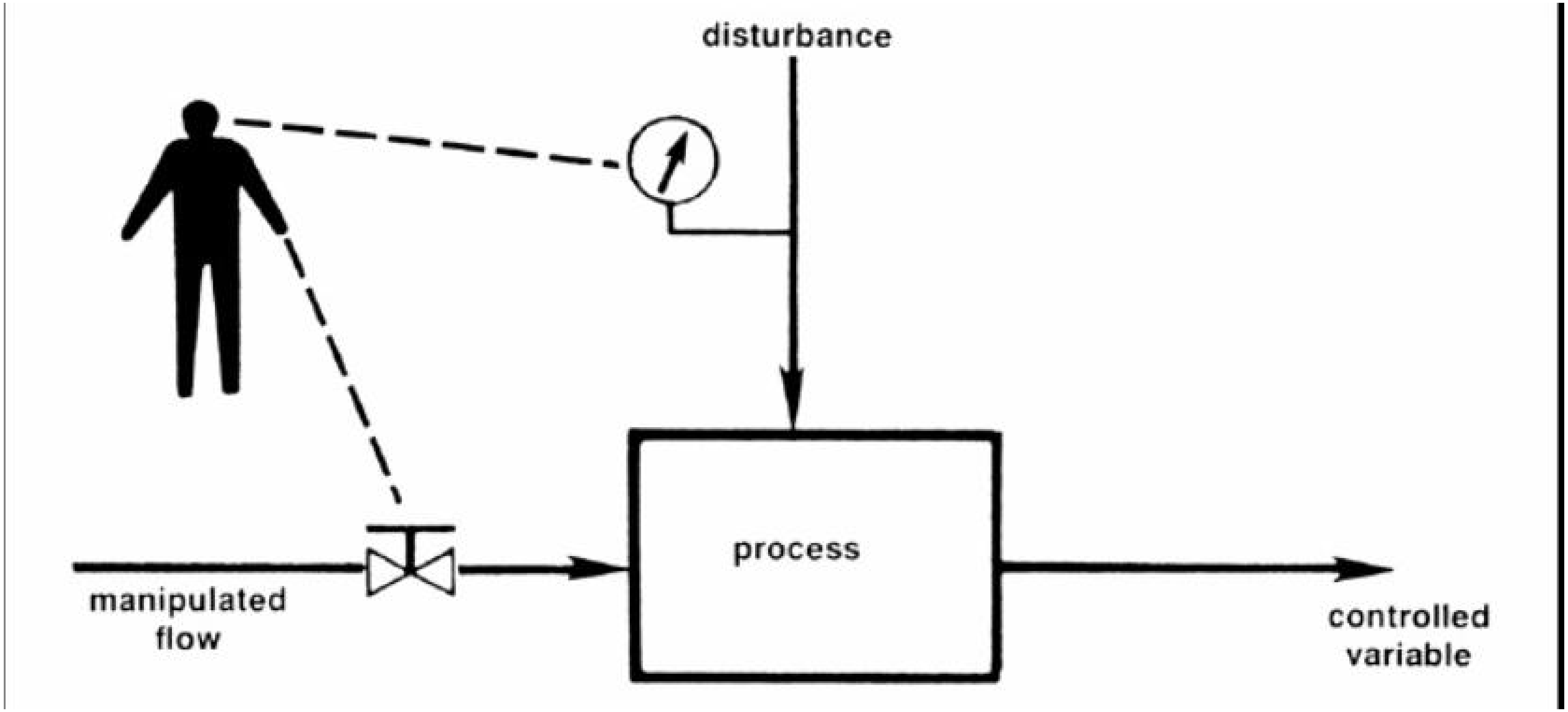
- Features of feedback



- ➢ Reactive / Error-driven
- ➢ Automatically compensates for disturbances (controller acts on error)
- ➢ Automatically follows change in desired state (set point can change)
- ➢ Can improve undesirable properties of system / plant

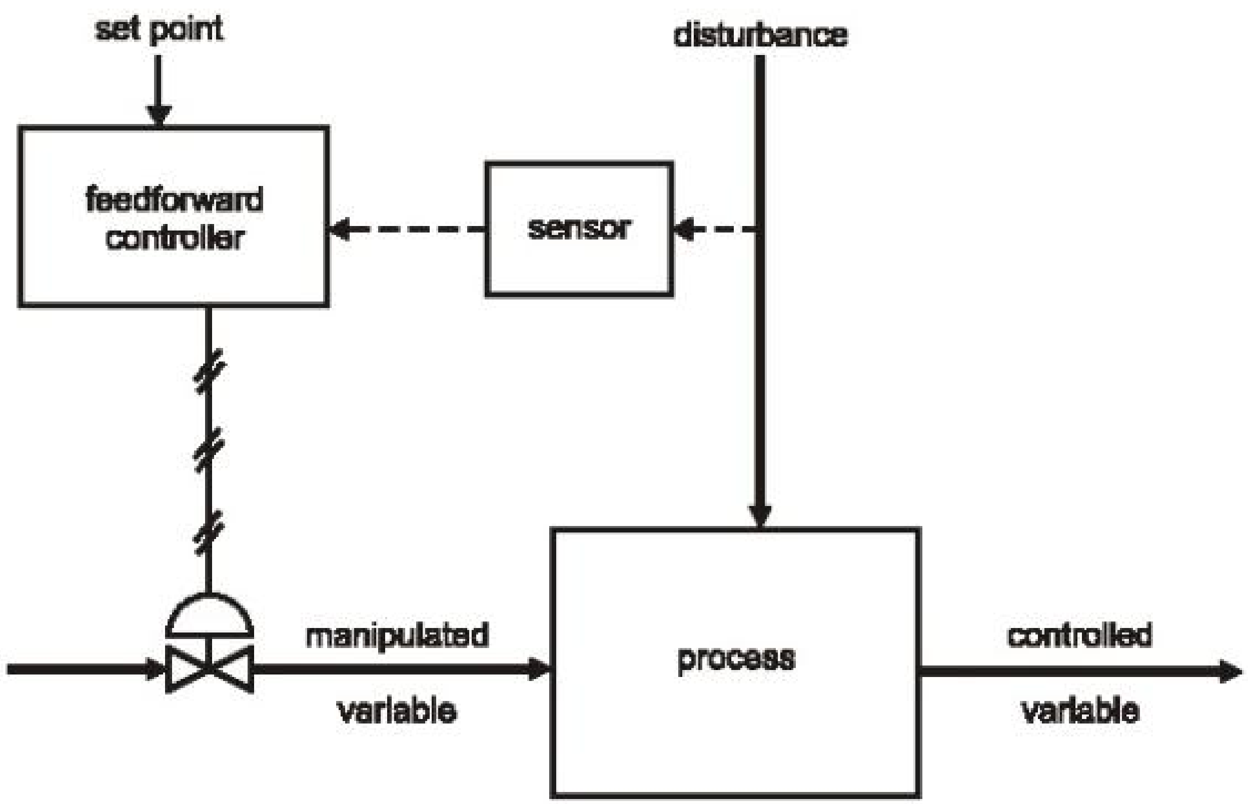
Feedback vs. Feedforward control

- manual feedforward control



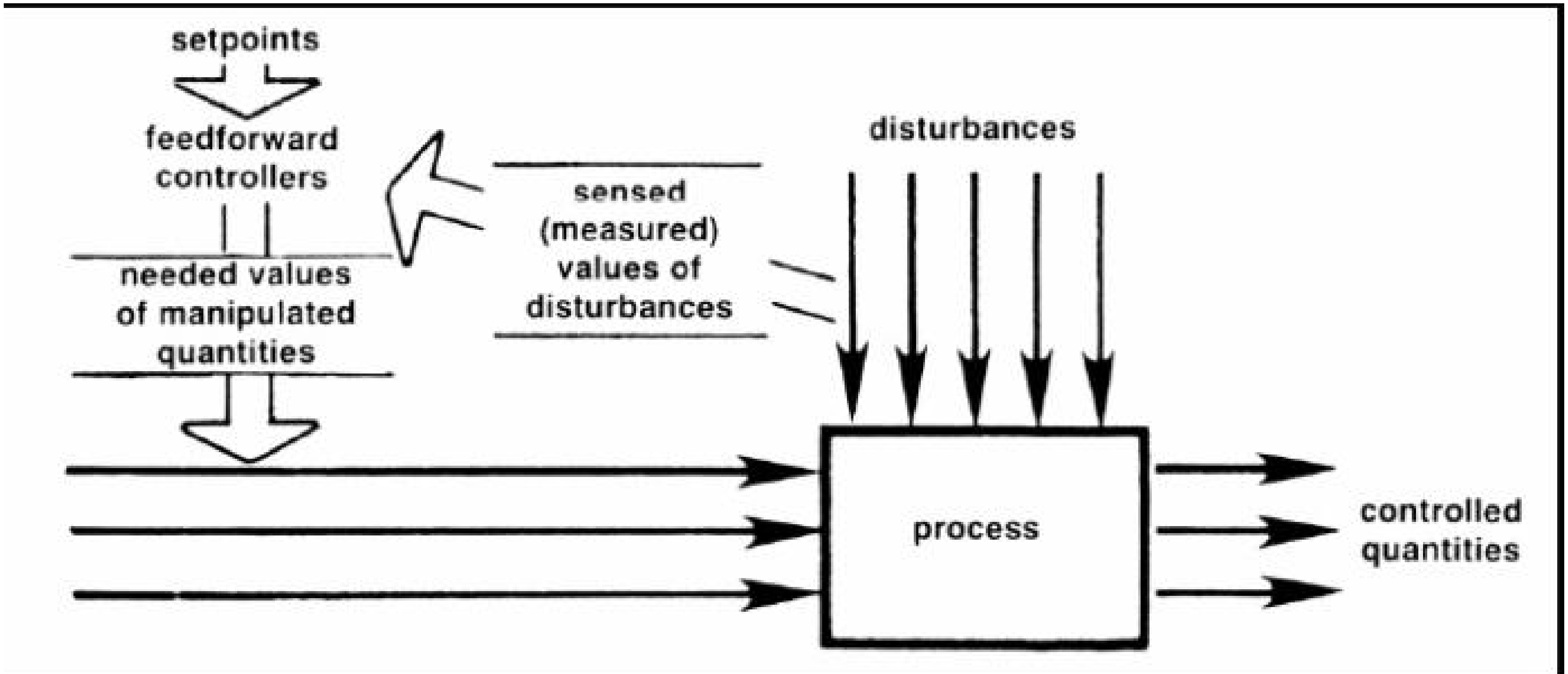
Composite control system

- feedforward control



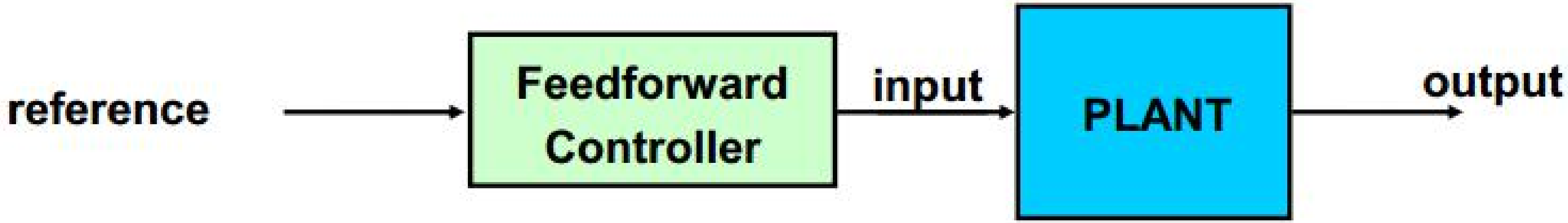
Composite control system

- feedforward control concept



Composite control system

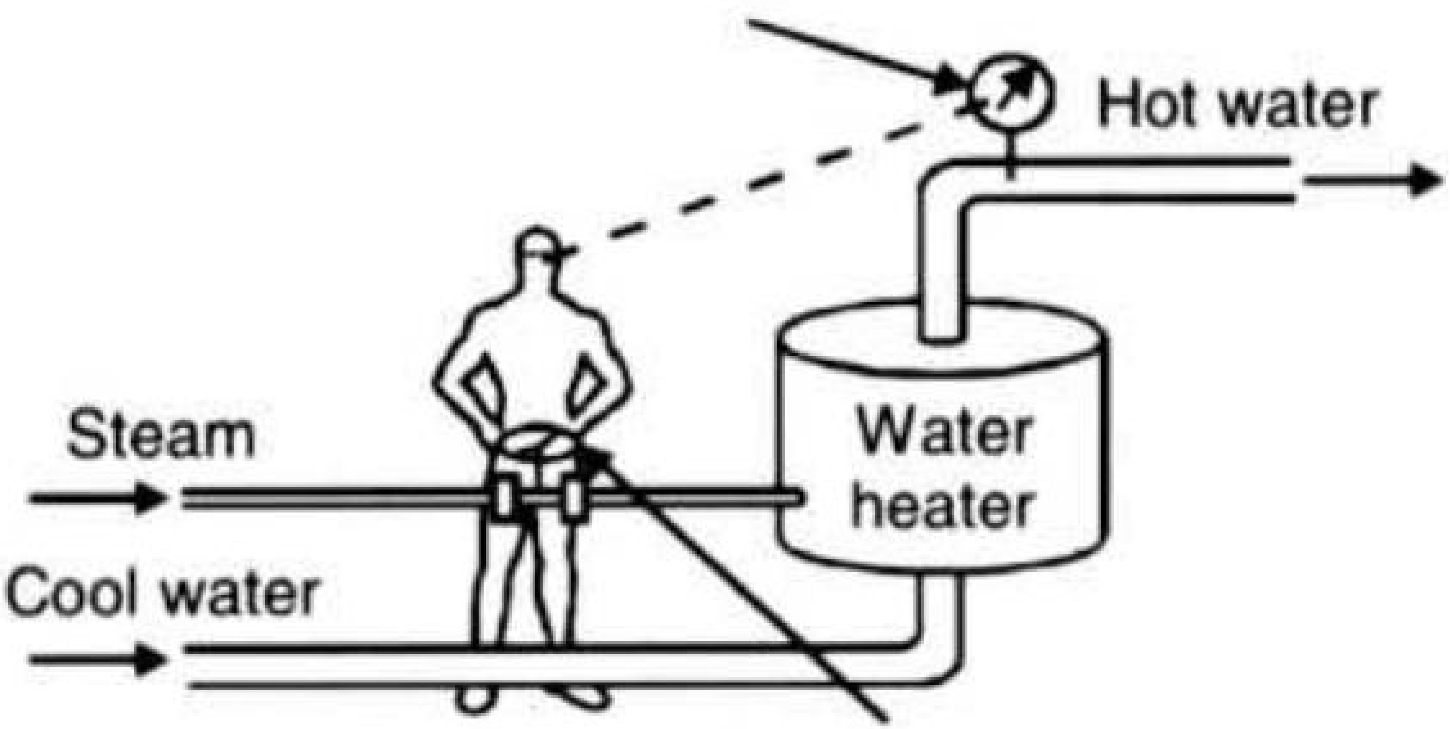
- Feedforward control



- ➢ Control element responds to change in measured disturbance in a pre-defined way
- ➢ Based on prediction of plant behavior (requires model)
- ➢ Can react before error actually occurs
  - Overcome sluggish dynamics and delays
  - Does not jeopardize stability

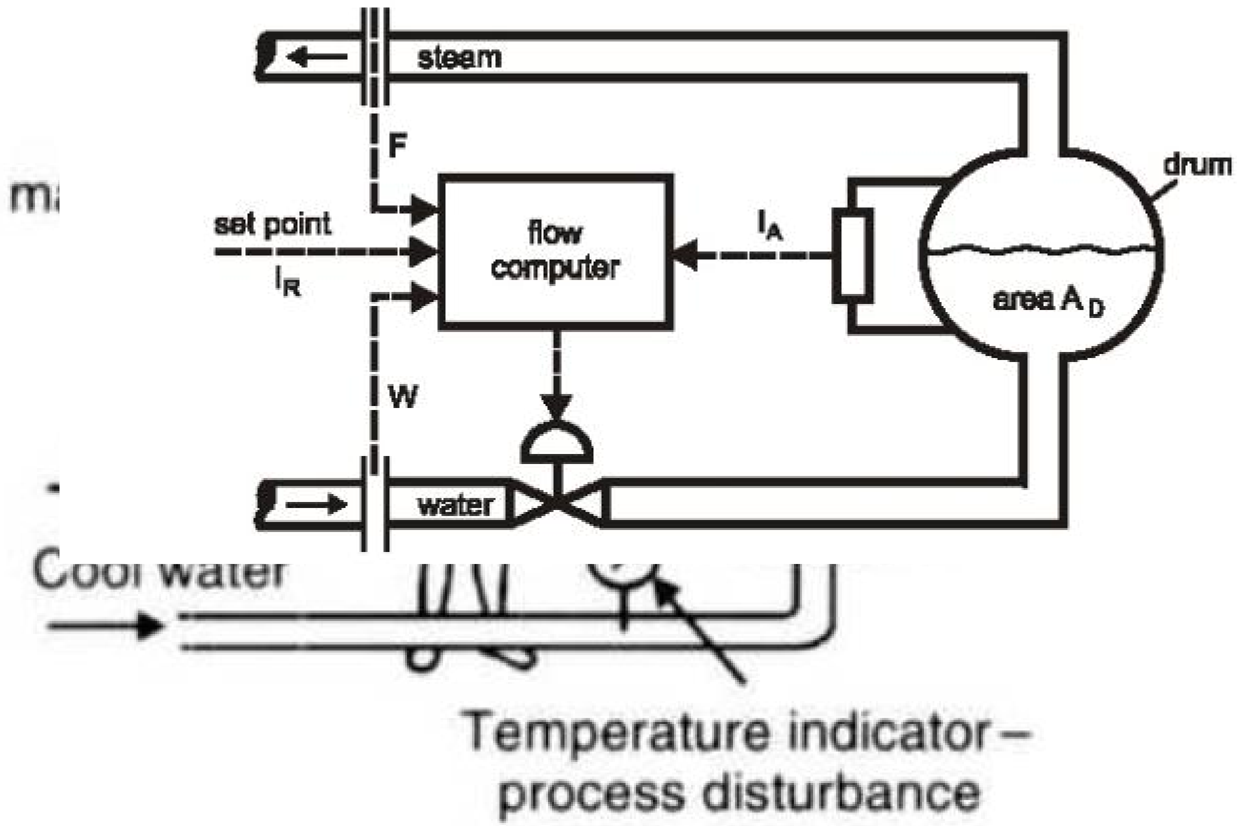
Composite control system

- feedback manual control



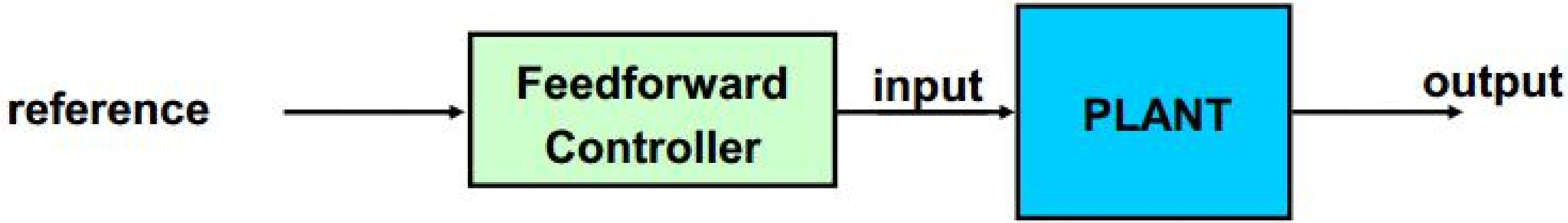
Composite control system

- feedforward manual control



Composite control system

- Limitations of feedforward control

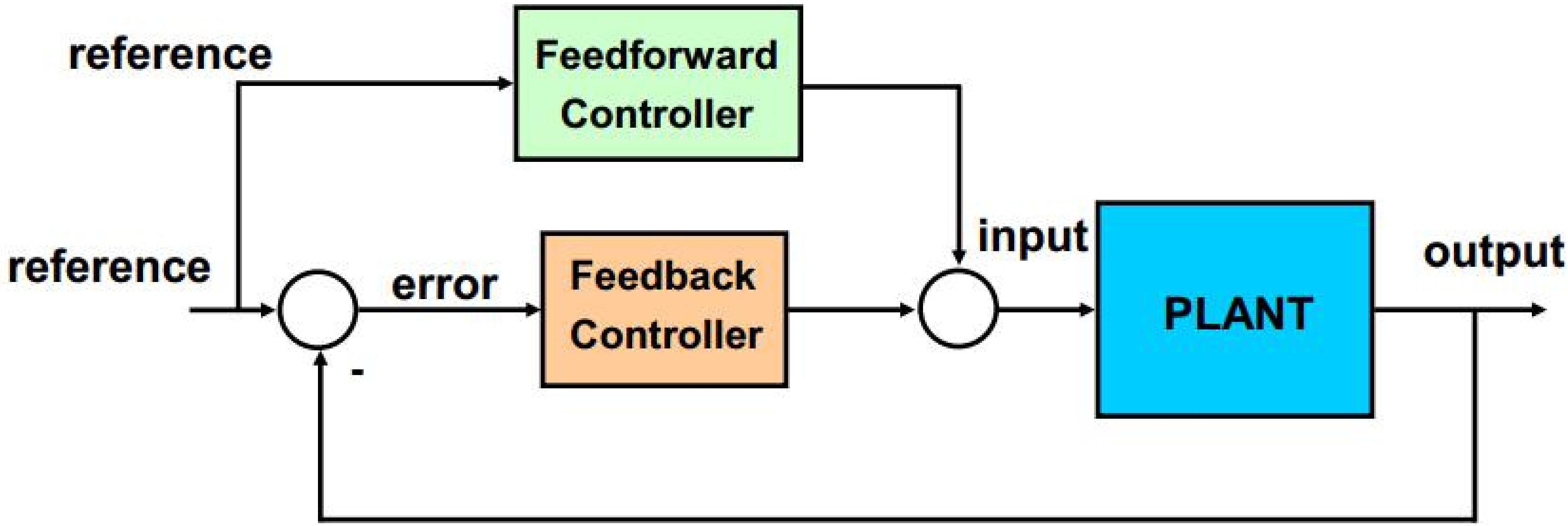


- ➢ Effects of disturbance or command input must be predictable
- ➢ May not generalize to other conditions
- ➢ Will not be accurate if the system changes

Composite control system

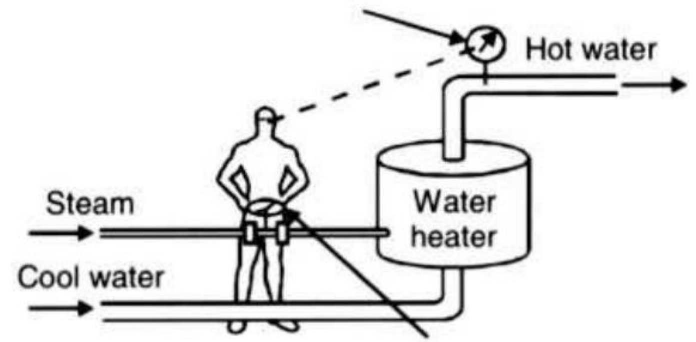
Feedforward and feedback are often used together

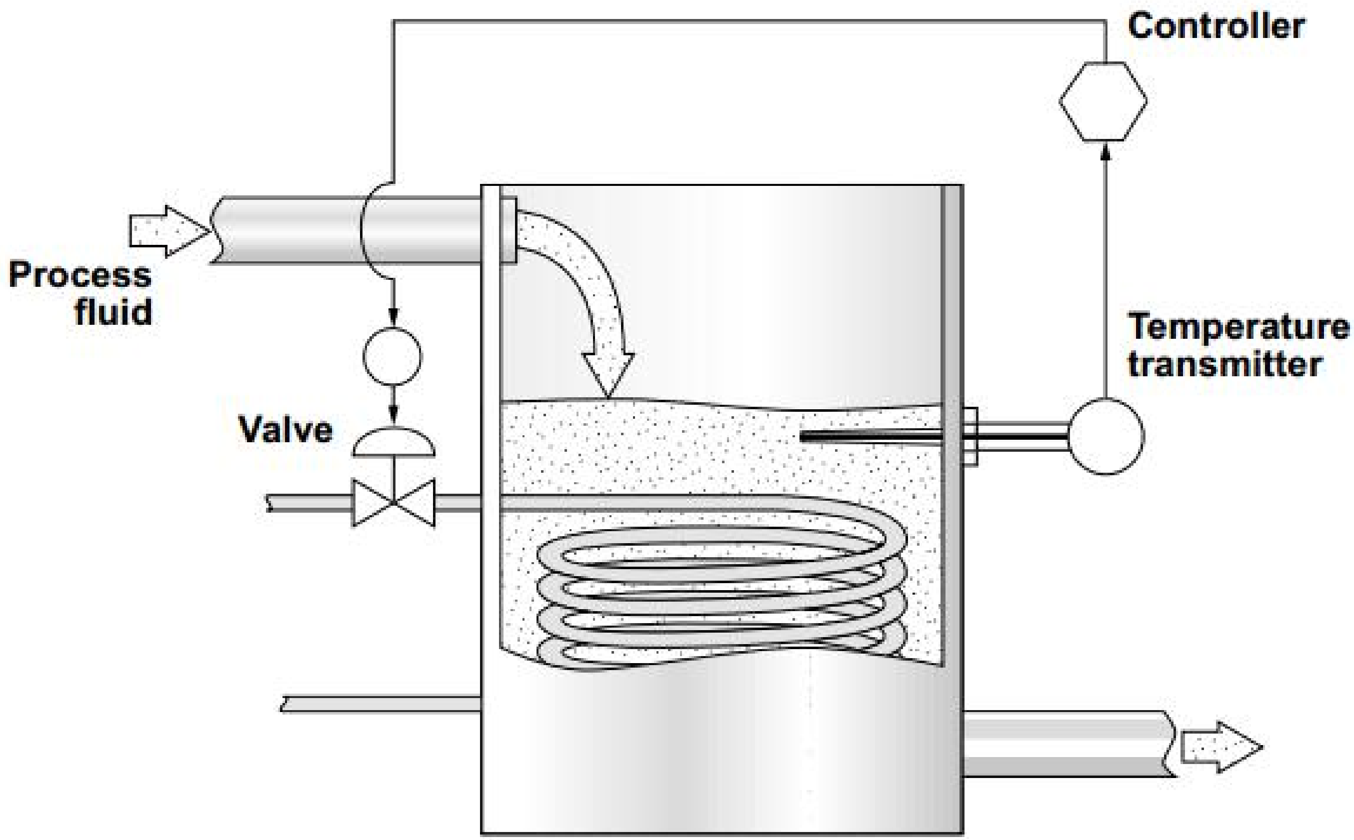
- Feedforward component provides rapid response
- Feedback component fills in the rest of the response accurately, compensating for errors in the model



Feedback control

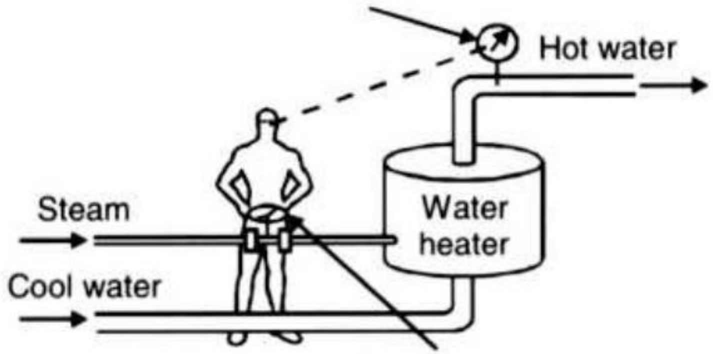
Exercise: water heater control

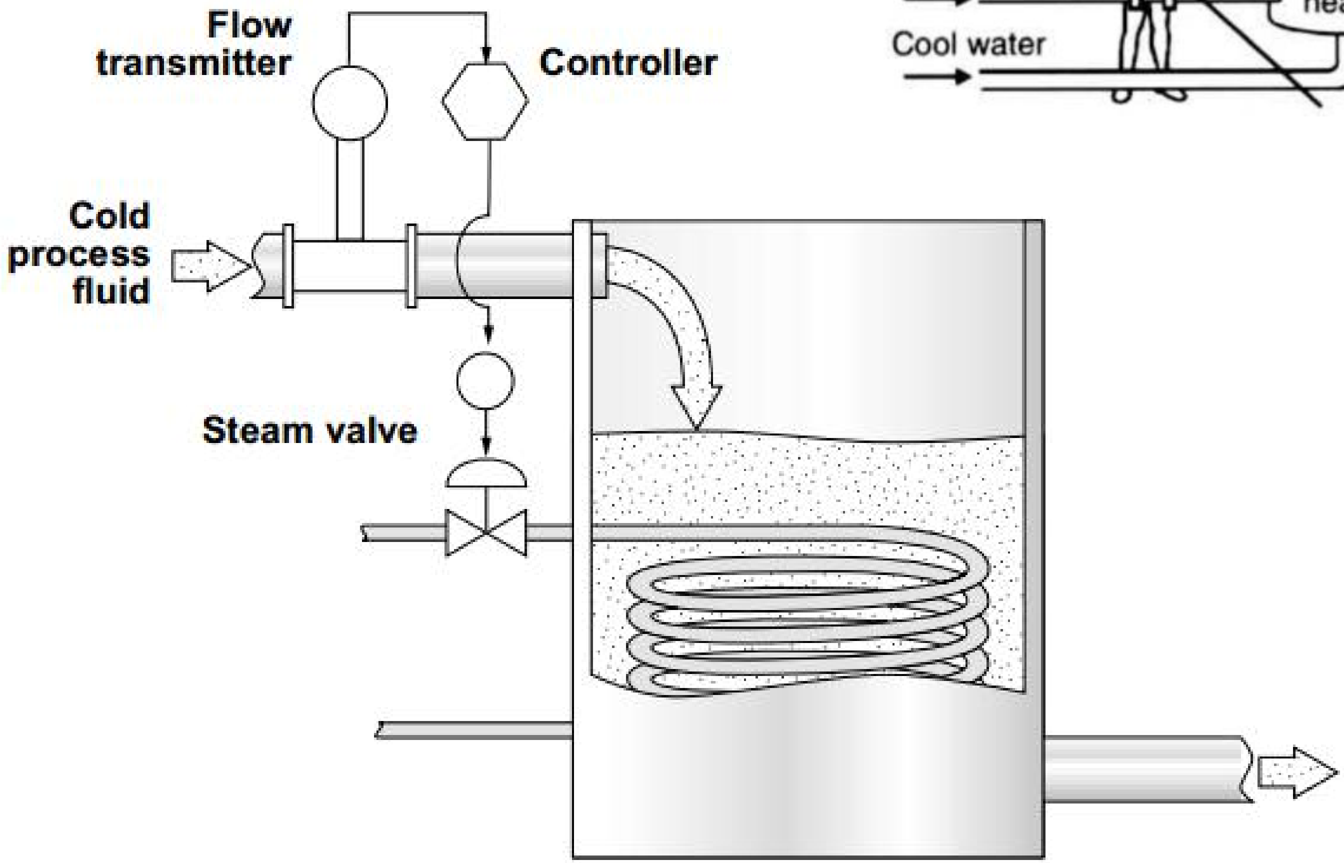




Feedforward control

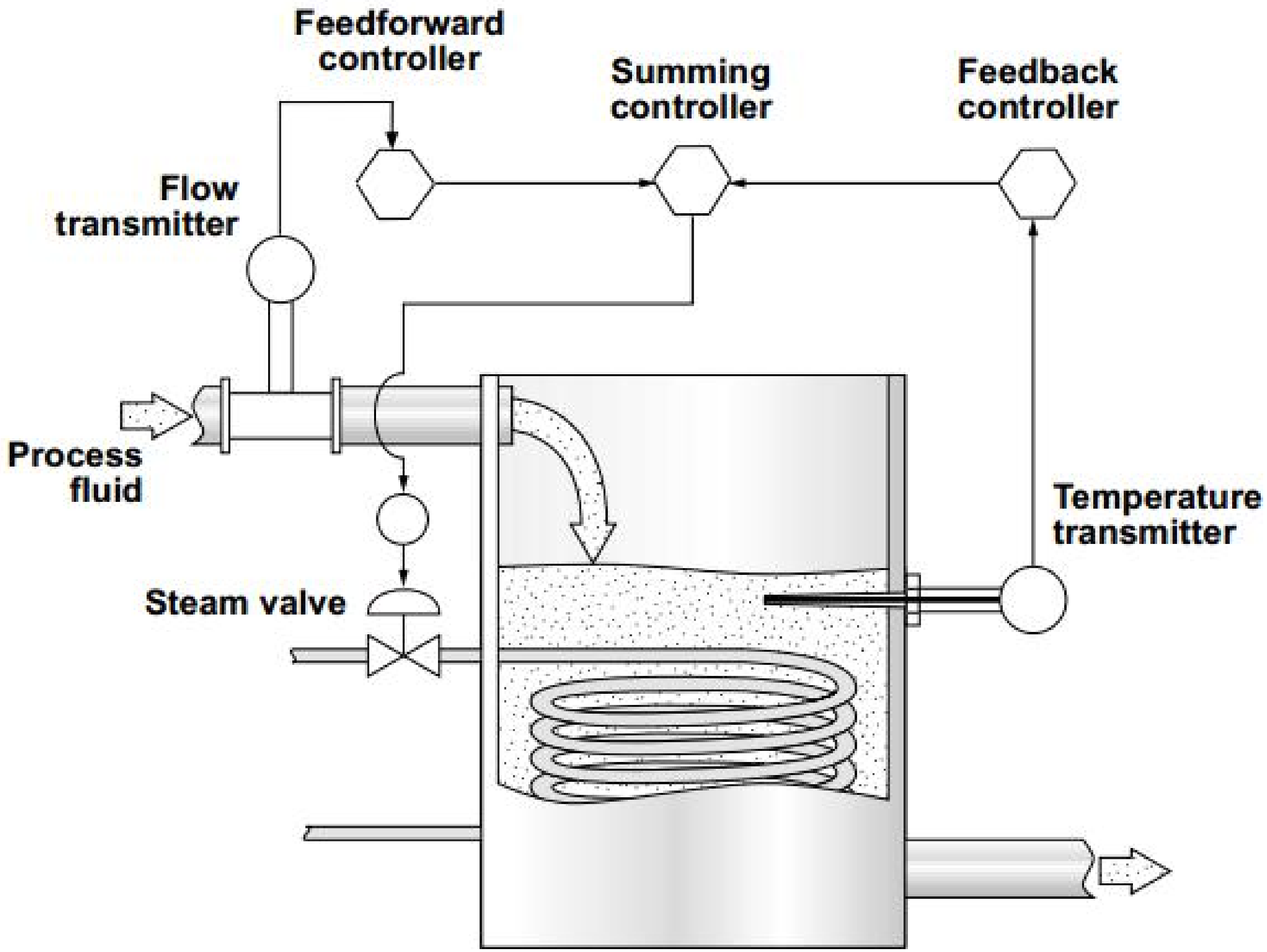
Exercise: water heater control





Feedforward + Feedback control

Exercise: water heater control

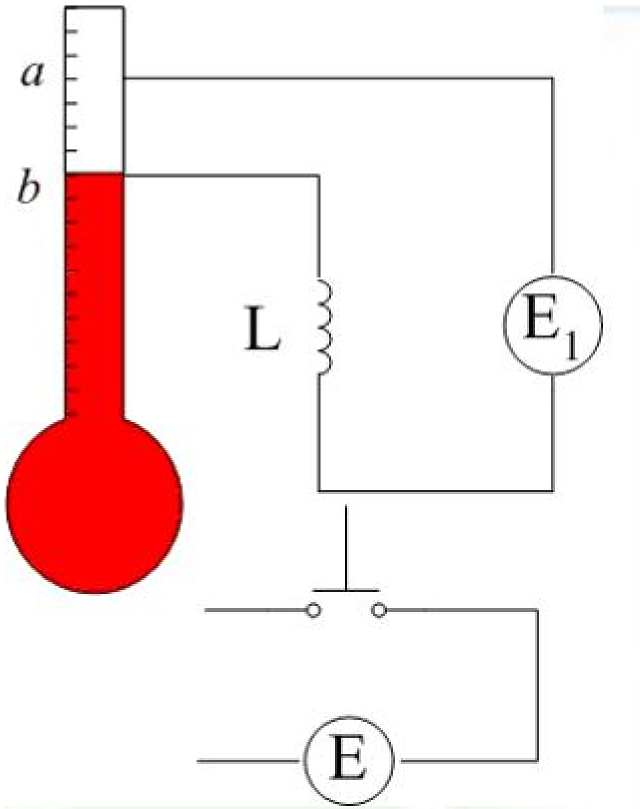


Exercise

1. Consider an electric oven in a typical modern kitchen. Identify the objective, plant, controlled variable, and the disturbances.
2. Imagine you own a backyard swimming pool! Describe a manual control system to measure pH and to add an acidic solution to adjust pH. Define the plant, controlled variable, and the disturbances.
3. Now automate the control of your swimming pool! Assume you have a tank of acid solution to pump into your pool to control pH.

Closed Loop (feedback) control

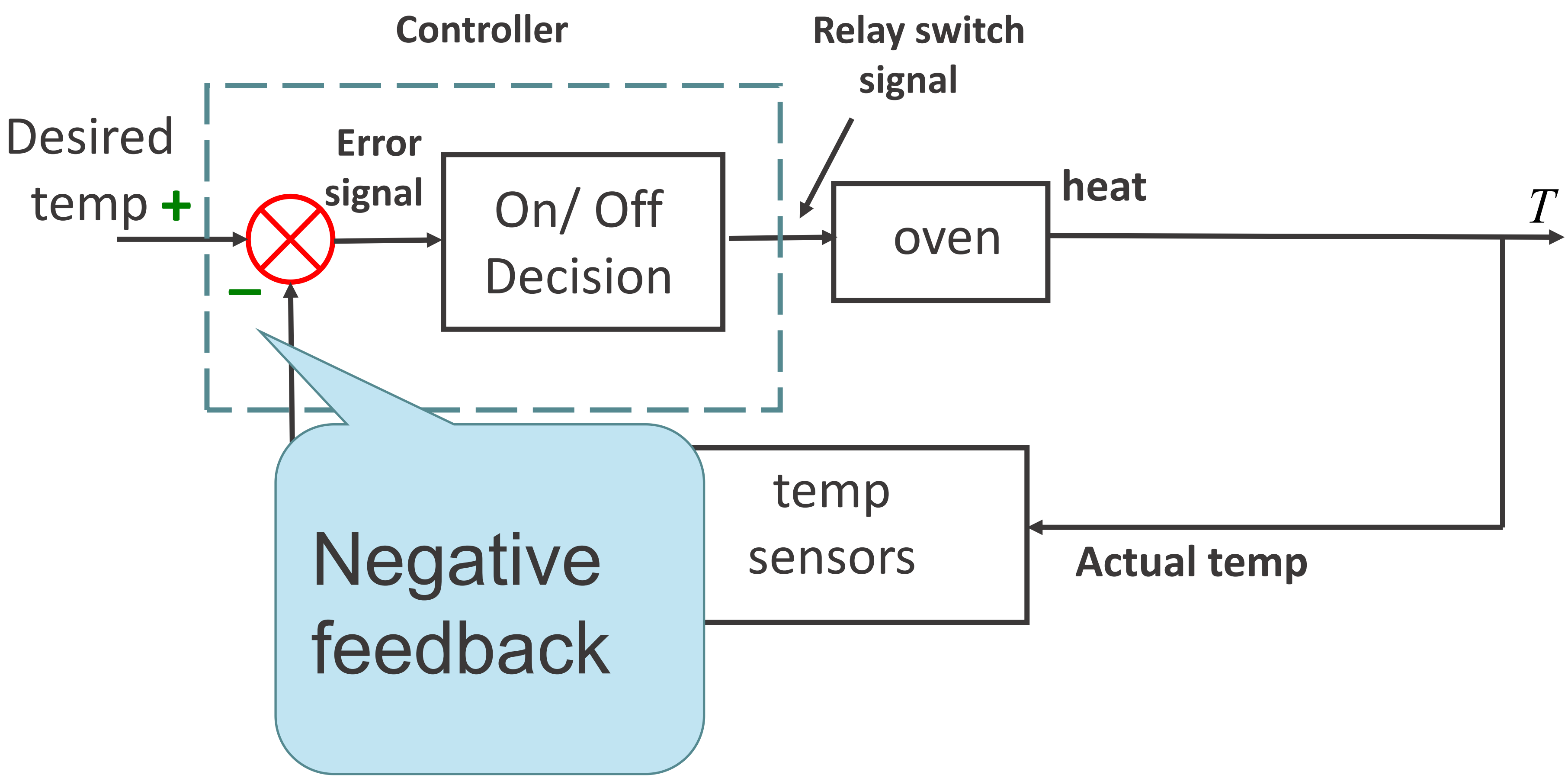
Exercise 1: Closed-loop Control – Electric oven



- If temperature of oven is below (or above) the desired value, oven turns on (turns off) until the temperature inside the output is slightly higher (lower) than the desired temperature.

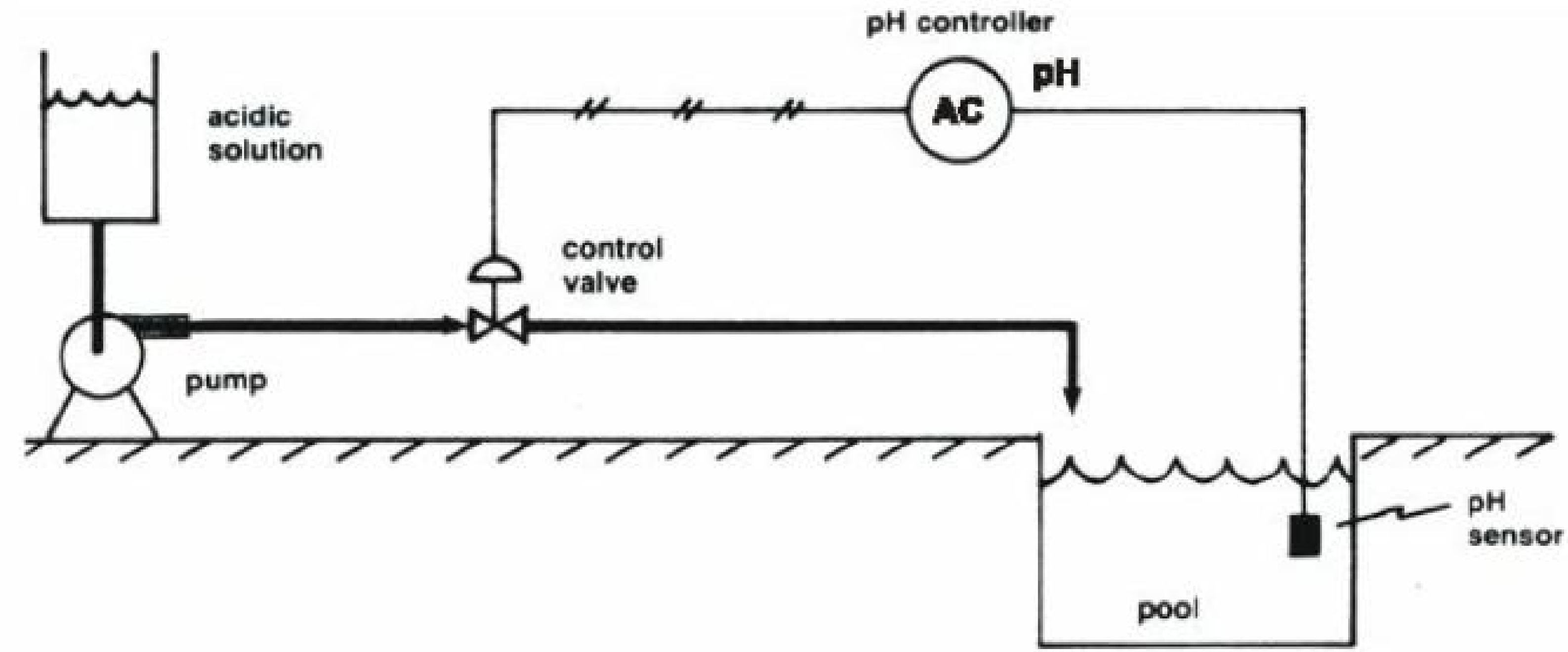
Closed Loop (feedback) control

Exercise 1: Closed-loop Control – electric oven



Closed Loop (feedback) control

Exercise 3: Automatic Control – Swimming pool

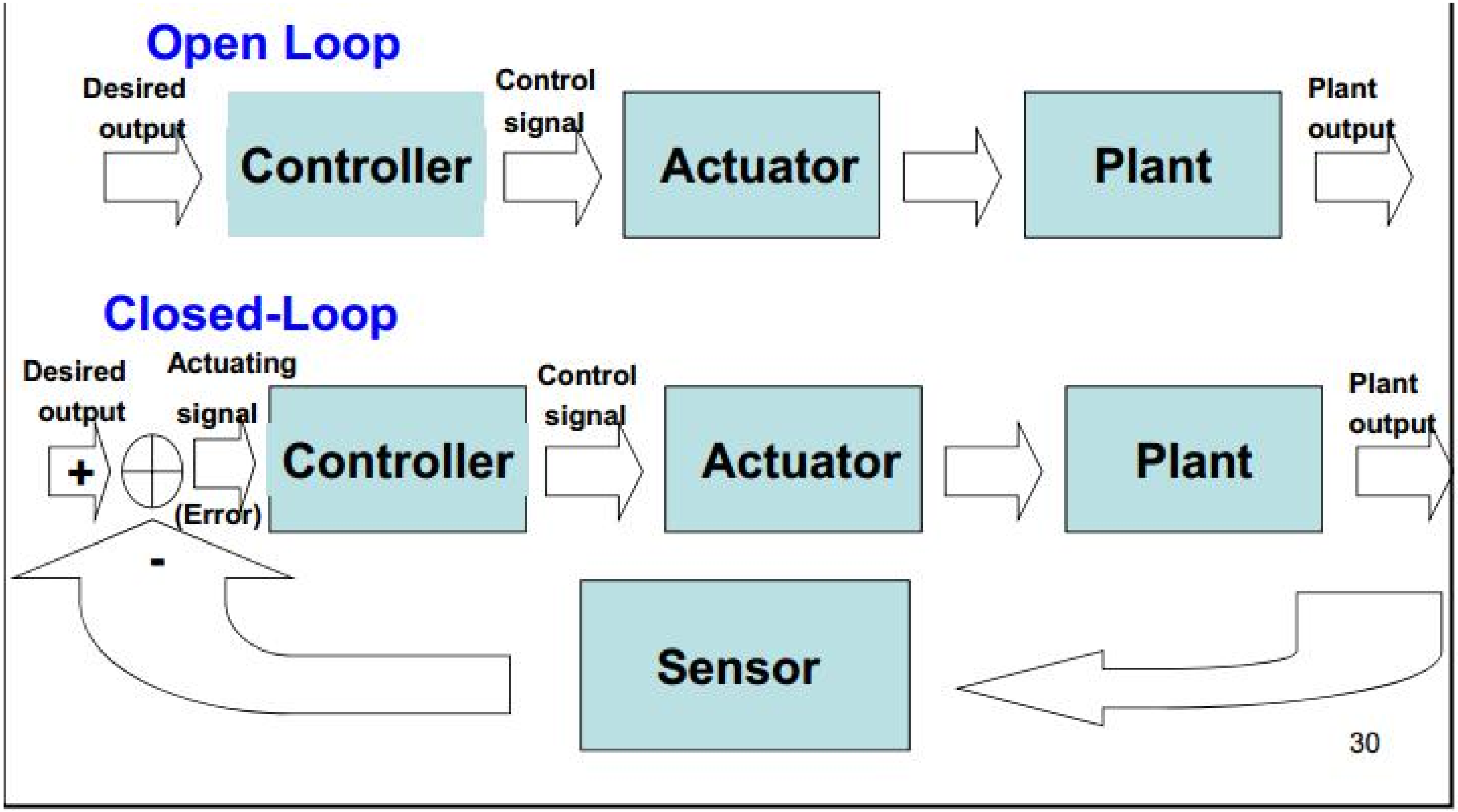


Classification of control systems

According to structure

- Open-loop control systems
- Closed-loop control systems
- Composite control systems

Open-loop / Closed-loop



Classification of control systems

According to type of reference input

- Constant-value control system

  (e.g. Water level control, DC motor speed control)

- Servo/tracking control system

  (e.g. Aircraft-autopilot, Guided missile)

- Programming control system

  (e.g. Numerically controlled machine)

Classification of control systems

According to type of reference input

- Servo/tracking control system

Guided missile

Classification of control systems

According to type of reference input

- Programming control system

Numerically controlled machine

Classification of control systems

According to system character with respect to time

- 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)

Classification of control systems

According to system character

- Linear system

  - principle of homogeneity and superposition

  - described by linear differential equation

- Nonlinear system

  - described by nonlinear differential equation

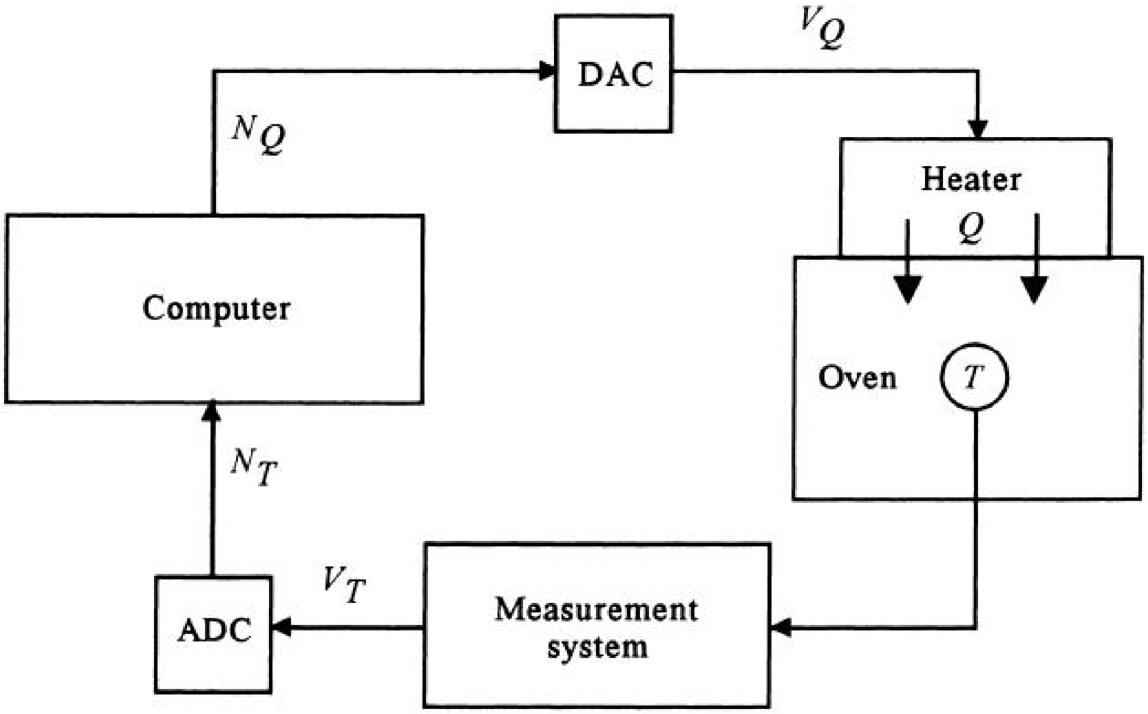
Classification of control systems

According to form of the signals

- Continuous-data control system
  - The signals are all functions of continuous time variable
- Discrete-data control system
  - The signals are in the form of either a pulse train or a digital code

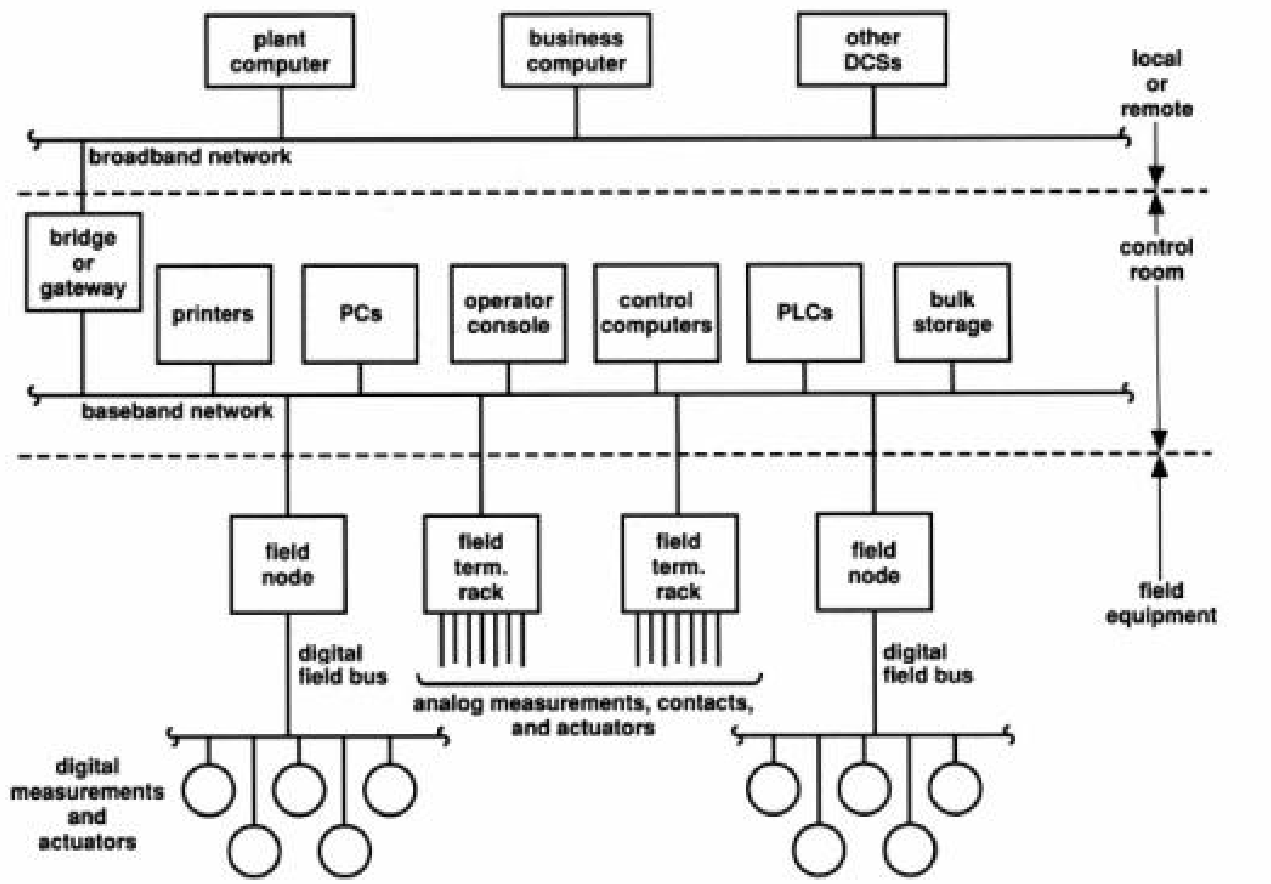
Classification of control systems

- This direct digital control system lets the computer perform the error detection and controller functions



Classification of control systems

- Distributed Control System (DCS)



Basic requirements for control systems

- The system is expected to be affected Only by control input, NOT by disturbance.

- Two-fold tasks:

  (1) how the system responses to the external input?

  (2) how the system resists disturbances?

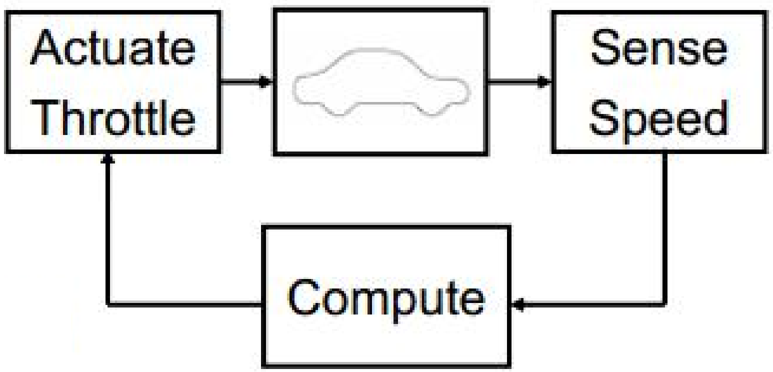
Basic requirements for control systems

- The variable used to measure the performance of the control system is the error, e(t), which is the difference between the input or reference value, r (t), and the controlled variable, c(t).

$$e(t) = r(t) - c(t)$$

Basic requirements for control systems

- Ensure stability
  - System maintains desired operating point (hold steady speed)
- Improve performance
  - System responds rapidly to changes (accelerate to 6 m/sec)



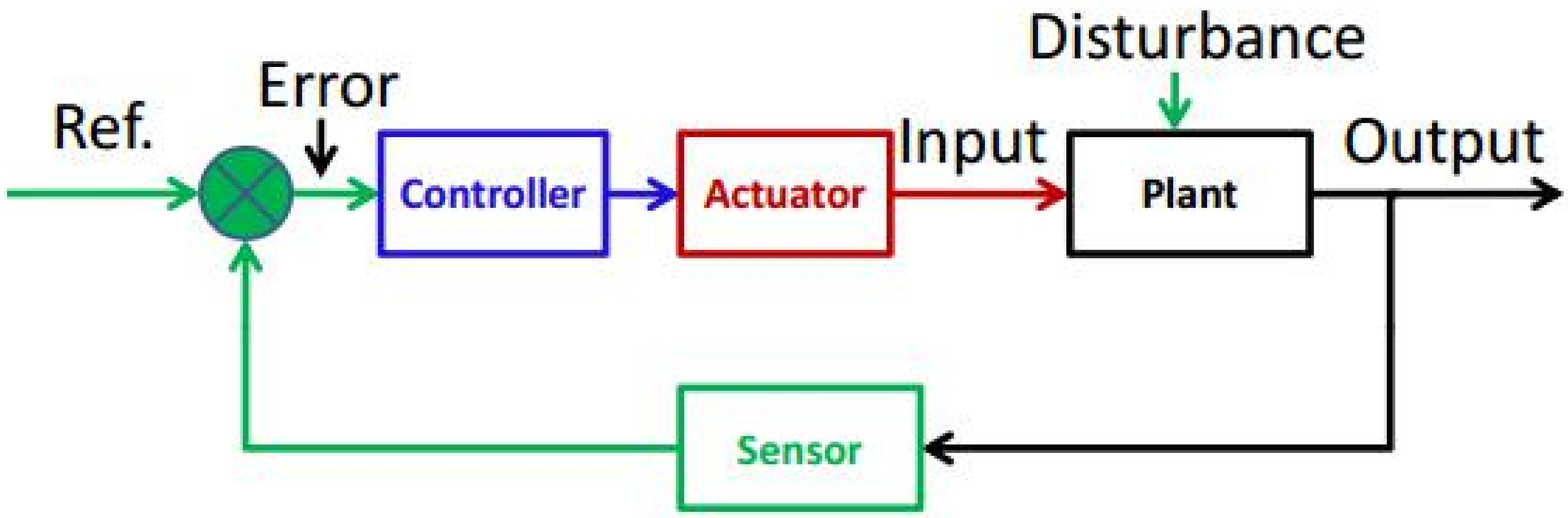
- Guarantee robustness
  - System tolerates perturbations in dynamics (mass, drag, etc.)

Basic requirements for control systems

A suitable control system should have some of the following properties:

1. Stability
2. Accuracy
3. Swiftness

Basic requirements for control systems



- Regulation process: From initial equilibrium state to a new equilibrium.

Basic requirements for control systems

- The whole regulation process can be divided into two stages:

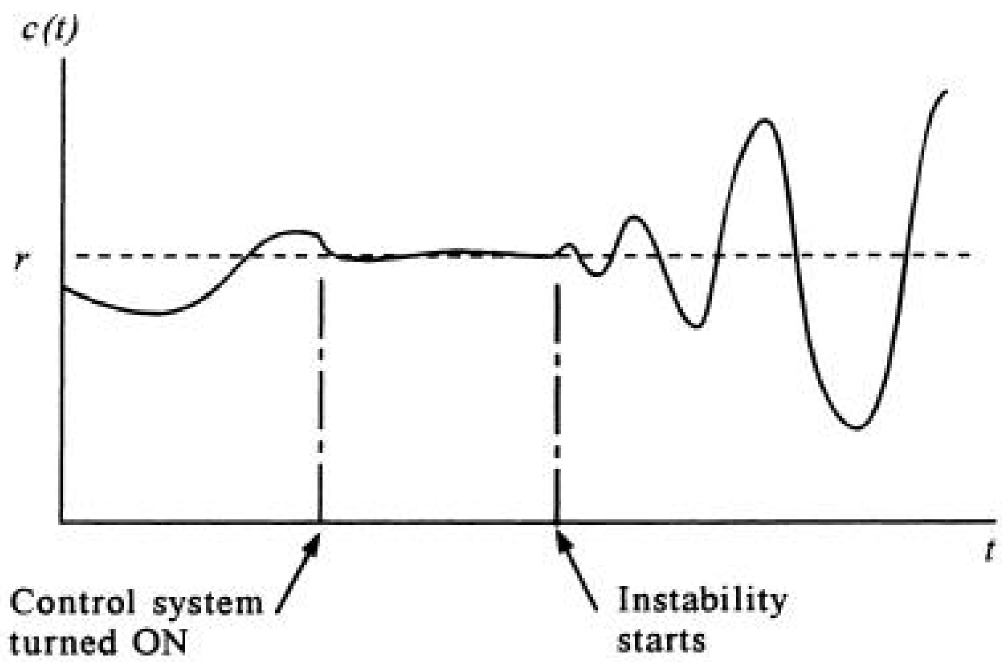
- Transient process in which the controlled variable goes from the initial state to the final state.

- steady-state process in which the system output stay at a new equilibrium state and maintain at a constant value.

Basic requirements for control systems

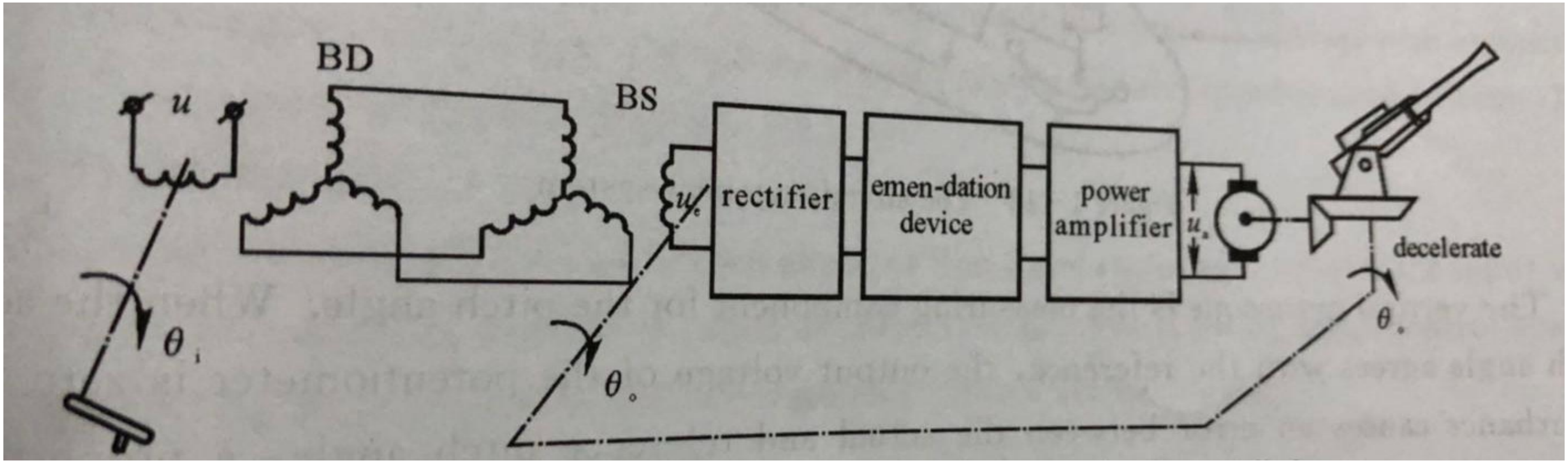
Definitions

1. Stability (**Basic requirement**): refers to ability of a system to recover equilibrium, i.e., convergence of transient process (converge)



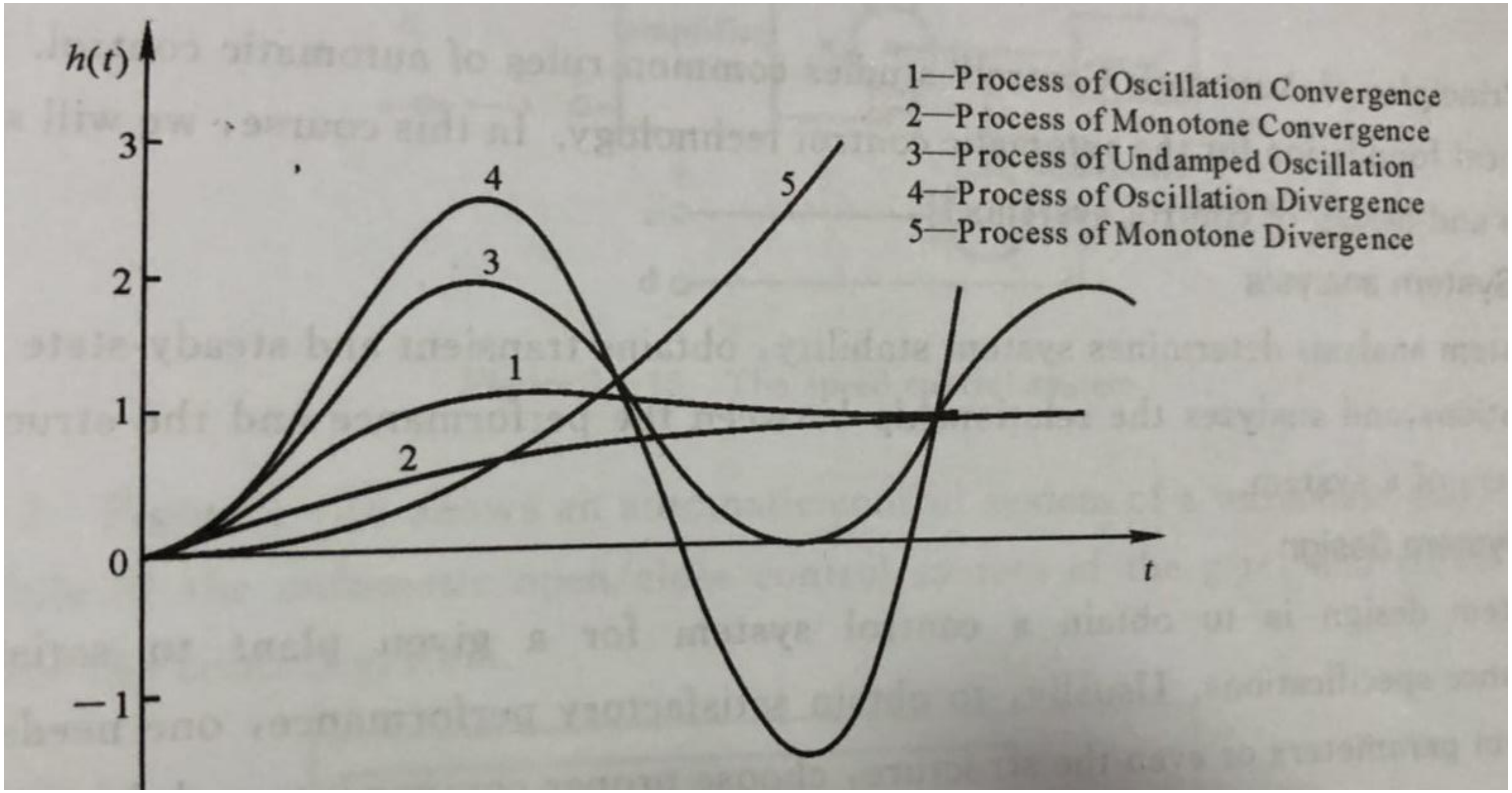
Basic requirements for control systems

1. Stability (**Basic requirement**): refers to ability of a system to recover equilibrium, (i.e., convergence of transient process)



Basic requirements for control systems

1. Stability



Basic requirements for control systems

1. Stability ---(converge)

2. Accuracy : refers to size of a steady-state error when the transient process ends. (small)

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

3. Swiftness: refers to duration of transient process (quick)

Basic requirements for control systems

Note

For a control system, the above three performance indices (stability, accuracy, swiftness) are sometimes contradictory.

In design of a practical control system, we always need to make compromise.

Engineering Control Problem

Determine the requirements of a certain control system.

↓

Draw block diagram

↓

Transform physical systems into math. Eqs. (Math. Modeling).

↓

Block diagram simplification.

↓

Analyze, design, and test the control system to ascertain that the desired requirements are fulfilled.

Summary

- Chapter 1:

  Control essentiality

  Examples of control systems

  Open-loop versus closed-loop control

  Component block diagram

- Next lecture:

  Time Response of Linear System

Assignment – Chapter 1

1. Consider an automatic gas-fired, home hot-water tank. Identify the controlled variable, the manipulated variable, and the disturbances.

Assignment – Chapter 1

2. Figure 1.2 shows the grain humidity control system. There is an optimal grinding humidity on which we can acquire the most flour. So, we need to add some water to grain to achieve the optimal grain humidity. Grain is conveyed with a constant flow under an auto valve which controls the water quantity. In this process, grain flow, initial grain humidity and water pressure consists of the disturbance of the grain humidity control system. In order to get better precision, feed forward control is adapted. Please draw the block diagram of the system.

Assignment – Chapter 1

Figure 1.2