Linear Control Systems
EET-302

Dr. Reenu George

Electrical & Electronics Engineering Department

Syllabus

CODE	COURSE NAME	CATEGORY	L	T	P	CREDIT
EET302	LINEAR CONTROL SYSTEMS	PCC	2	2	0	4

Preamble: This course aims to provide a strong foundation on classical control theory. Modelling, time domain analysis, frequency domain analysis and stability analysis of linear systems based on transfer function approach will be discussed. The compensator design of linear systems is also introduced.

Prerequisite : Basics of Circuits and Networks, Signals and Systems

Course Outcomes : After the completion of the course the student will be able to:

CO 1	Describe the role of various control blocks and components in feedback systems.
CO 2	Analyse the time domain responses of the linear systems.
CO 3	Apply Root locus technique to assess the performance of linear systems.
CO 4	Analyse the stability of the given LTI systems.
CO 5	Analyse the frequency domain response of the given LTI systems.
CO 6	Design compensators using time domain and frequency domain techniques.

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Course Objective	Course Outcome
COBJ 1 To demonstrate the role of various control blocks and components in feedback systems	**CO 1** Ability to demonstrate the role of various control blocks and components in feedback systems.
COBJ 2 To analyze the time domain responses and the stability of the given LTI systems.	**CO 2** Ability to analyze the time domain responses and the stability of the given LTI systems.
COBJ 3 To design and analyze the closed-loop performance of LTI systems.	**CO 3** Ability to design and assess the performance of LTI systems.
COBJ 4 To analyze the frequency domain response of the given LTI systems.	**CO 4** Ability to analyze the frequency domain response of the given LTI systems.
COBJ 5 To design compensators using time domain and frequency domain techniques.	**CO 5** Ability to design compensators using time domain and frequency domain techniques.

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Module 1

Feedback Control Systems (9 hours)

Open loop and closed loop control systems- Examples of automatic control systems - Transfer function approach to feed back control systems – Effect of feedback

Control system components – Control applications of DC and AC servo motors, Tacho generator, Synchro, Gyroscope and Stepper motor

Controllers- Types of controllers & Compensators - Transfer function and basic characteristics of lag, lead and lag-lead phase compensators.

Module 2

Performance Analysis of Control Systems (9 hours)

Time domain analysis of control systems: Time domain specifications of transient and steady state responses- Impulse and Step responses of first and second order systems- Pole dominance for higher order systems.

Error analysis: Steady state error analysis and error constants -Dynamic error coefficients.

Stability Analysis: Concept of BIBO stability and Asymptotic stability- Time response for various pole locations- stability of feedback systems - Routh's stability criterion- Relative stability

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Module 3

Root Locus Analysis and Compensator Design (11 hours)

Root locus technique: Construction of Root locus- stability analysis- effect of addition of poles and zeroes- Effect of positive feedback systems on Root locus

Design of Compensators: Design of lag, lead and lag-lead compensators using Root locus technique.

PID controllers: PID tuning using Ziegler-Nichols methods.

Simulation based analysis: Introduction to simulation tools like MATLAB/ SCILAB or equivalent for Root locus based analysis (Demo/Assignment only)

Module 4

Frequency domain analysis (9 hours)

Frequency domain specifications- correlation between time domain and frequency domain responses

Polar plot: Concepts of gain margin and phase margin- stability analysis

Bode Plot: Construction- Concepts of gain margin and phase margin- stability analysis, Effect of Transportation lag and Non-minimum phase systems.

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Module 5

Nyquist stability criterion and Compensator Design using Bode Plot (9 hours)

Nyquist criterion: Nyquist plot- Stability criterion- Analysis

Introduction to Log magnitude vs. phase plot and Nichols chart (concepts only) - Compensator design using Bode plot: Design of lag, lead and lag-lead compensator using Bode plot.

Simulation based analysis: Introduction to simulation tools like MATLAB/ SCILAB or equivalent for various frequency domain plots and analysis (Demo/Assignment only).

Textbooks

1. Nagarath I. J. and Gopal M., Control System Engineering, 5/e, New Age Publishers
2. Ogata K, Modern Control Engineering, 5/e, Prentice Hall of India.
3. Nise N. S, Control Systems Engineering, 6/e, Wiley Eastern
4. Dorf R. C. and Bishop R. H, Modern Control Systems, 12/e, Pearson Education

Reference Books

1. Kuo B. C, Automatic Control Systems, 7/e, Prentice Hall of India
2. Desai M. D., Control System Components, Prentice Hall of India, 2008
3. Gopal M., Control Systems Principles and Design, 4/e, Tata McGraw Hill.
4. Imthias Ahamed T. P, Control Systems, Phasor Books, 2016

Syllabus

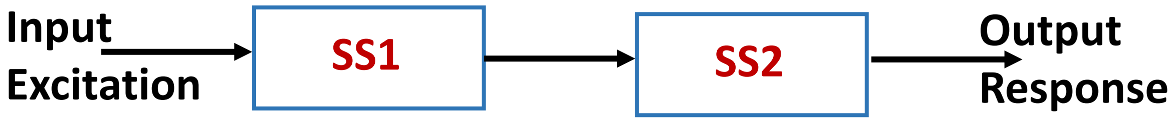
Course Contents and Lecture Schedule:

Module	Topic coverage	No. of Lectures
1	**Feedback Control Systems (9 hours)**	
1.1	Terminology and basic structure of Open loop and Closed loop control systems- Examples of Automatic control systems (block diagram representations only)	2
1.2	Transfer function approach to feed back control systems- Effect of feedback- Characteristic equation- poles and zeroes- type and order.	2
1.3	Control system components: Transfer functions of DC and AC servo motors –Control applications of Tacho generator, Synchro, Gyroscope and Stepper motor	3
1.4	Need for controllers: Types of controllers – Feedback, Cascade and Feed forward controllers Compensators: Transfer function and basics characteristics of lag, lead, and lag-lead phase compensators	2

What is a System?

- A collection of physical, biological, or abstract components that perform an intended objective together.
- System can be thought of as an entity that produces outputs (also called response) corresponding to inputs (also called excitation) provided to it.

- System can be collection of multiple systems called as sub-systems.



Examples of Systems

Motor

- Input- Electrical Energy
- Output- Mechanical Energy

Fan

- Input- Electrical Energy
- Output-Mechanical Energy

Electric Iron box

- Input- Electrical Energy
- Output-Heat Energy

Vehicles

- Input- Acceleration/Deceleration
- Output- Vehicle displacement

Classification of Systems

- Depending on features and applications variety of classifications are possible
- Important classifications are:

  * Linear and non-linear systems

  * Static and dynamic systems

  * Time invariant and time-variant systems

  * Casual and non-causal systems

In this course, we deal with Linear time-invariant systems- LTI

- A system can be mathematically represented as a mapping,

$$f: u(t) \longrightarrow y(t) \text{ i.e., } y(t) = f(u(t))$$

Linear Vs Non-Linear Systems

Linear Systems

- System output varies linearly with the system input
- Satisfy homogeneity and superposition

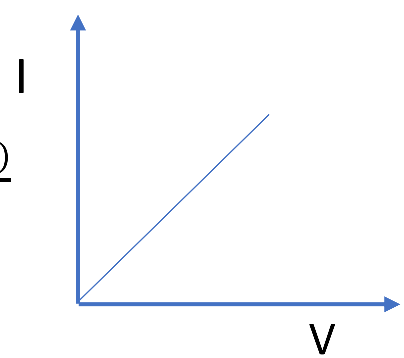
Consider a system whose outputs for two inputs $u_1(t)$ and $u_2(t)$ are

$$y_1(t) = f(u_1(t)), y_2(t) = f(u_2(t))$$

This system is said to be linear if

$$f(c_1\, u_1(t) + c_2\, u_2(t)) = c_1\, f(u_1(t)) + c_2\, f(u_2(t))$$
$$= c_1\, y_1(t) + c_2\, y_2(t))$$

- Eg.: Resistor $I(\mathrm{t}) = \frac{V(t)}{R}$



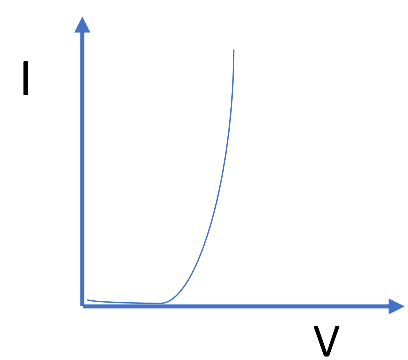
Non-Linear Systems

- System output does not vary linearly with the system input
- Do not satisfy homogeneity and superposition

This system is said to be non-linear if

$$f(c_1\, u_1(t) + c_2\, u_2(t)) \neq c_1\, f(u_1(t)) + c_2 f(u_2(t)) \neq c_1\, y_1(t) + c_2\, y_2(t))$$

- Eg.: Diode $I(t) = I_0(e^{V(t)/\tau} - 1)$



Static Vs Dynamic Systems

Static Systems

- At any time, the output of the system depends only on the present system input
- Memoryless systems
- $y(t) = f(u\ (t))$
- Eg.: Resistor-$I(\text{t}) = \frac{V(t)}{R}$

Dynamic Systems

- System output depends on present as well as past inputs
- System with memory
- $y(t) = f(u\ (t), u(t-1), u(t-2) \ldots)$
- Eg.: Inductor $I(t) = \frac{1}{L}\int_0^t V(t)dt$

Time Invariant Vs Time variant Systems

Time invariant Systems

- Output of the system is independent of the time at which the input is applied.
- $y(t) = f(u\ (t)) \Longrightarrow y(t+\delta) = f(u\ (t+\delta))$
- Eg.: An ideal Resistor-

$$I(\text{t}) = \frac{V(t)}{R} \quad \Rightarrow$$

$$I(\text{t} + \delta) = \frac{V(t+\delta)}{R}$$

Time variant Systems

- Output of the system varies dependent on the time at which input is applied
- $y(t) = f\big(u\ (t)\big) \not\Rightarrow \quad y(t+\delta) = f(u\ (t+\delta))$
- Eg.: Aircraft- Mass (M) of aircraft changes as fuel is consumed
- Acceleration $a(t) = \frac{F(t)}{M(t)}$

Casual Vs Non-casual Systems

Casual Systems

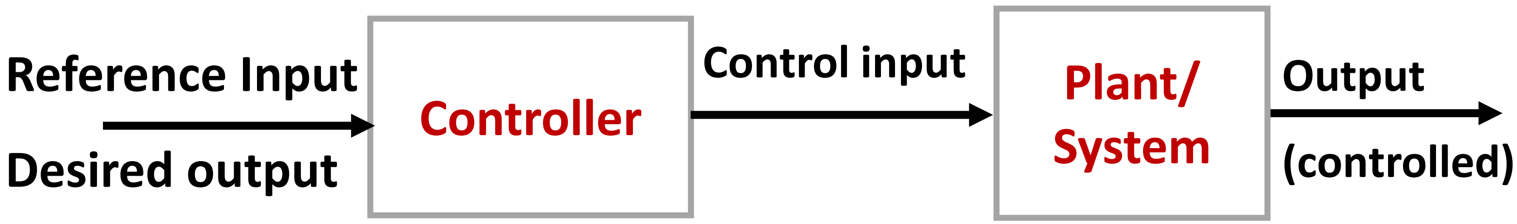
- Output of the system is only dependent on input already applied (present or past)
- Non-anticipatory system
- $y(t) = f(u\ (t), u(t-1)\ \ldots)$
- Eg.: Motor or Generator

Non-causal Systems

- Output of the system depends on future inputs as well
- Systems anticipates future inputs based on past
- $y(t) = f(u\ (t), u(t+1)\ \ldots)$
- Eg.: Weather forcasting

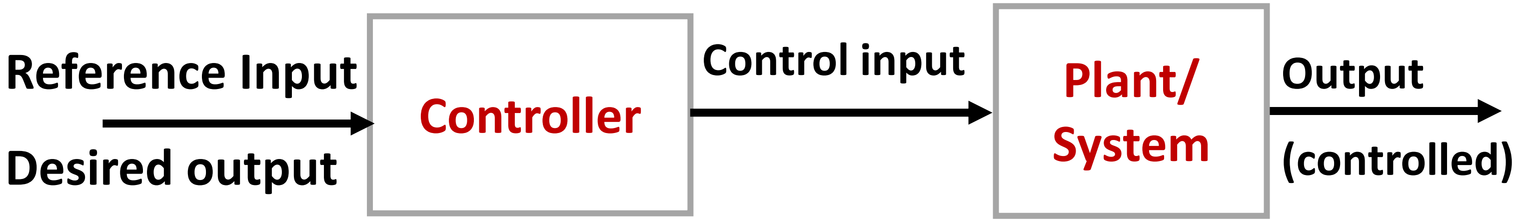
Control Systems

- Control - Making a system behave as desired
- A system or mechanism which directs the input to other systems and regulates their output

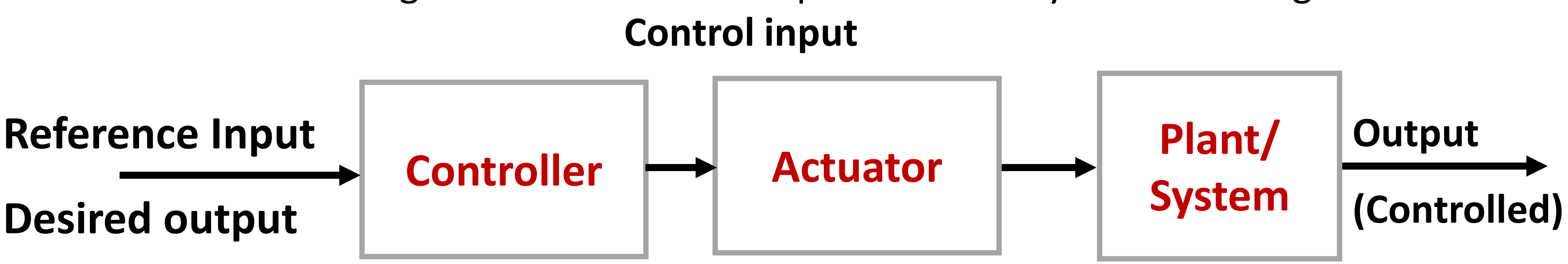


- Reference Input - external signal applied to the control system, which is the desired output
- Controller - a device or software that regulates the output of the system based on feedback or desired setpoints
- Control input - which the controller generates based on what is the desired reference
- Plant/system - the central component whose output variable is to be controlled
- Controlled output- variable or condition of the plant, which is controlled

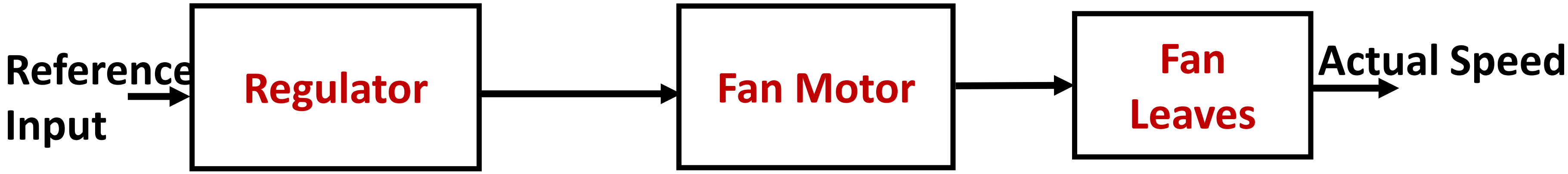
Open Loop Control Systems



- Output has no effect on the control action – open loop control systems
- Output is not compared with the reference input
- A fixed operating condition for each reference input
- Accuracy of the system depends on the calibration
- In the presence of disturbance, an open loop control system will not perform the desired task
- Utilizes an actuating device to control the process directly without using feedback



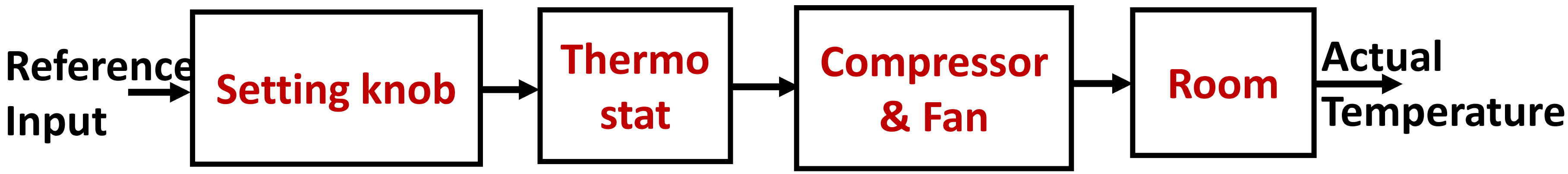
Example of Control System



- Identify

1. The process or plant
2. Output variable
3. Reference input
4. Controller
5. Control input
6. Actuator

Example of Control System



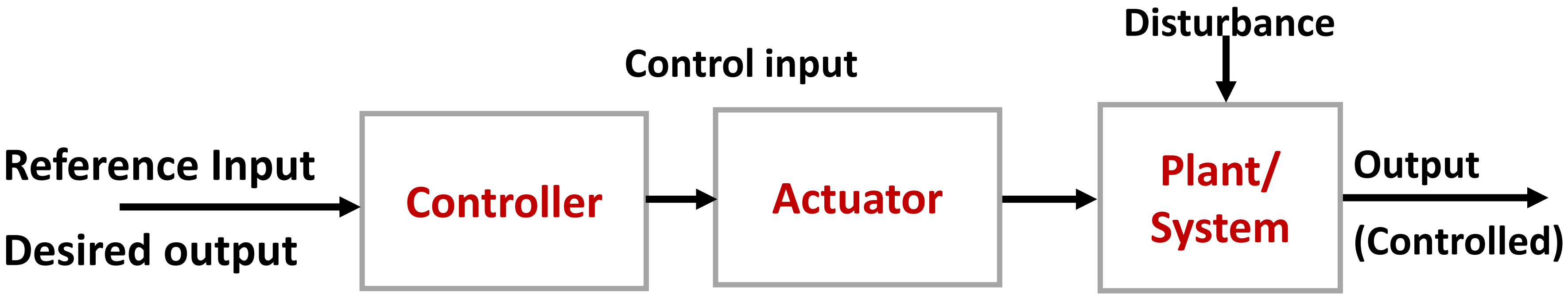
- Identify

1. The process or plant
2. Output variable
3. Reference input
4. Controller
5. Control input
6. Actuator

- What happens when people enter or leave the room?

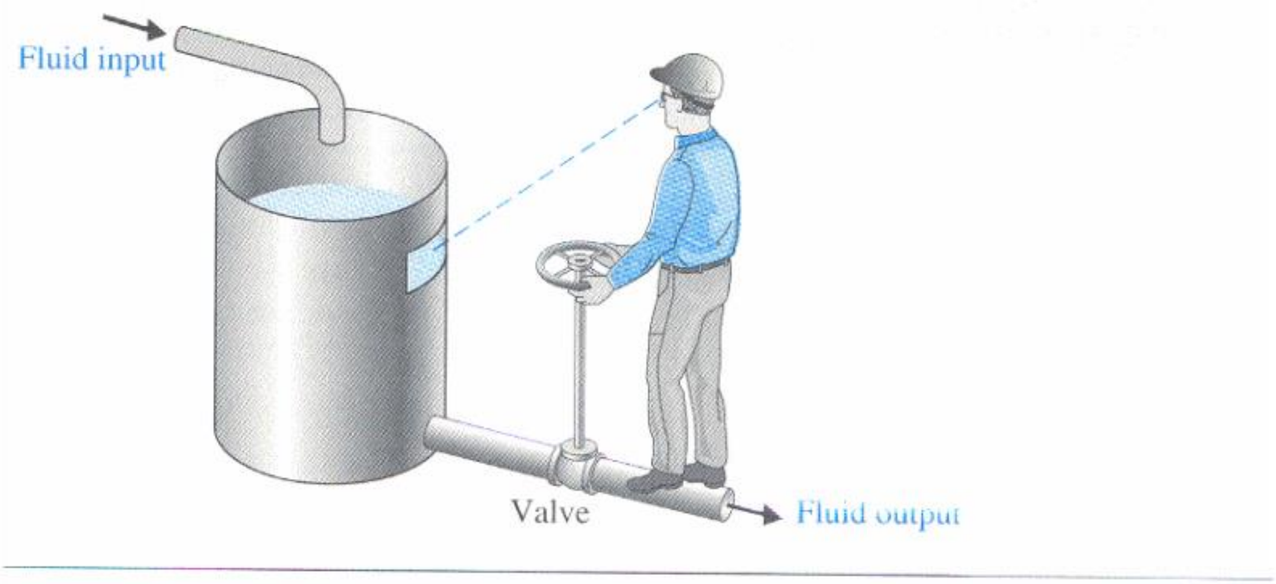
Disturbance

- Unwanted signals which affect the output of the system



- In the presence of disturbance, an open loop control system will not perform the desired task.

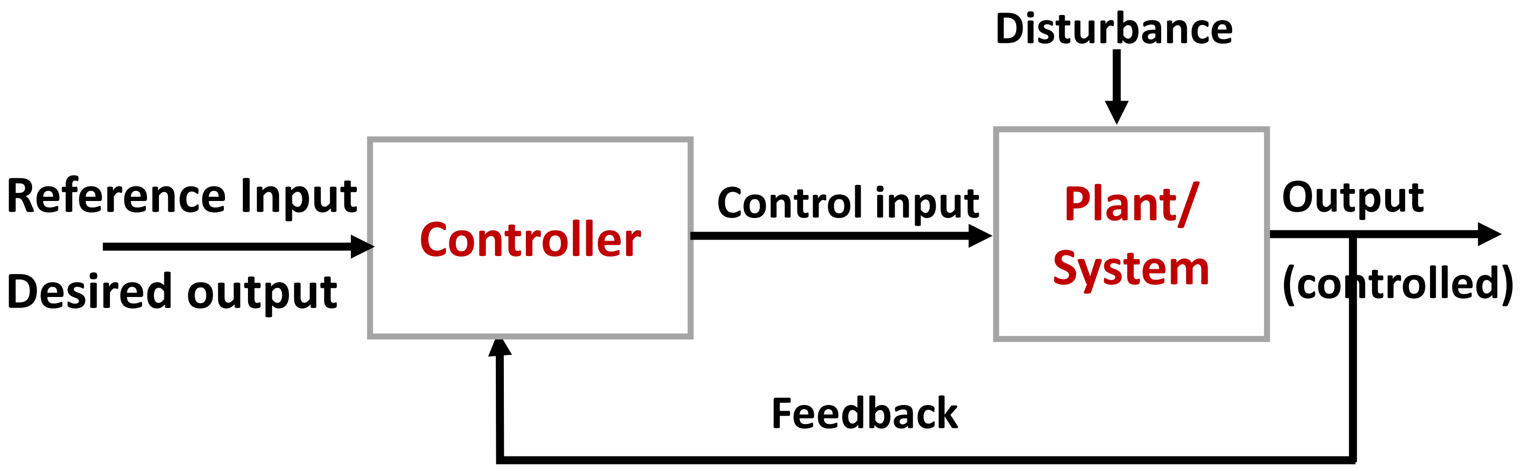
Closed loop/Feedback/Automatic Control Systems

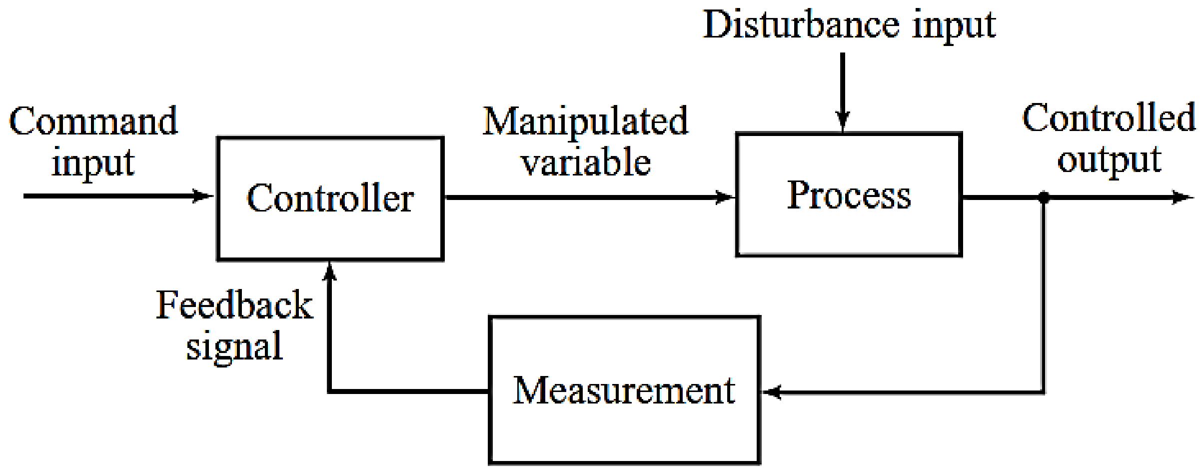


In this control system:
The *reference* is a desired level of fluid that operator is instructed to maintain.
The *actuator* is the valve that opens or closes the fluid flow out.
The *sensor* is visual.
The *controller* is the operator.

Feedback in Control

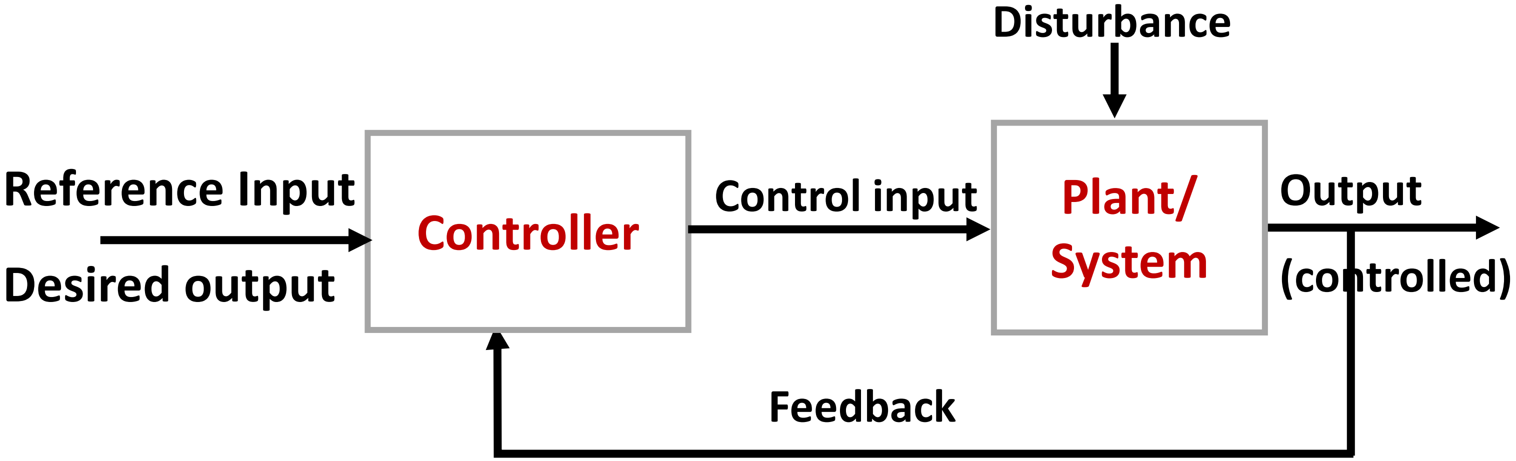
Closed loop control systems- feedback control systems



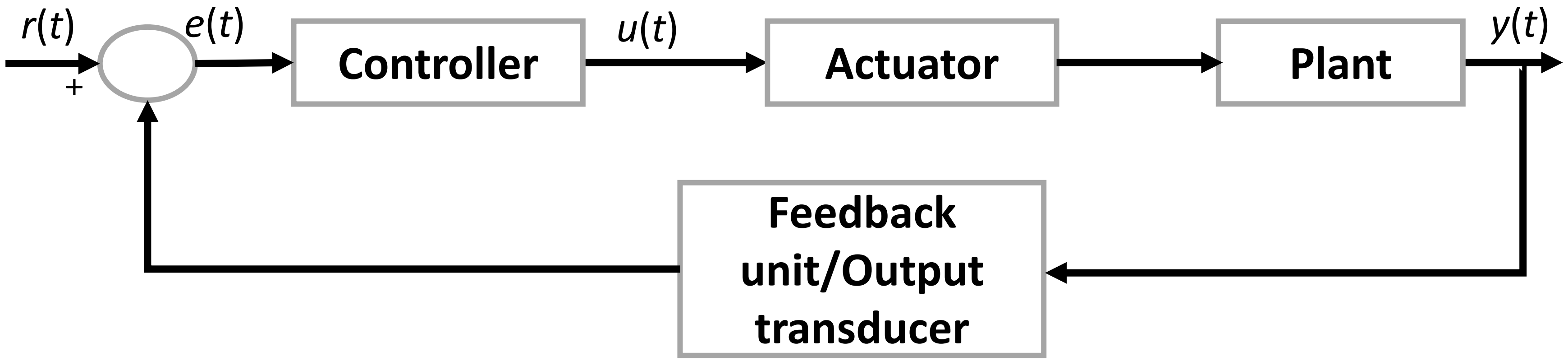


Feedback in Control

- Feedback senses the output of the plant and gives a signal which can be compared to the reference
- Controller action changes based on the feedback
- The difference between the actual and desired values is used to determine the amount of control inputs, also known as the manipulated variable
- Feedback makes the system response relatively insensitive to external disturbances and internal variations in system parameters

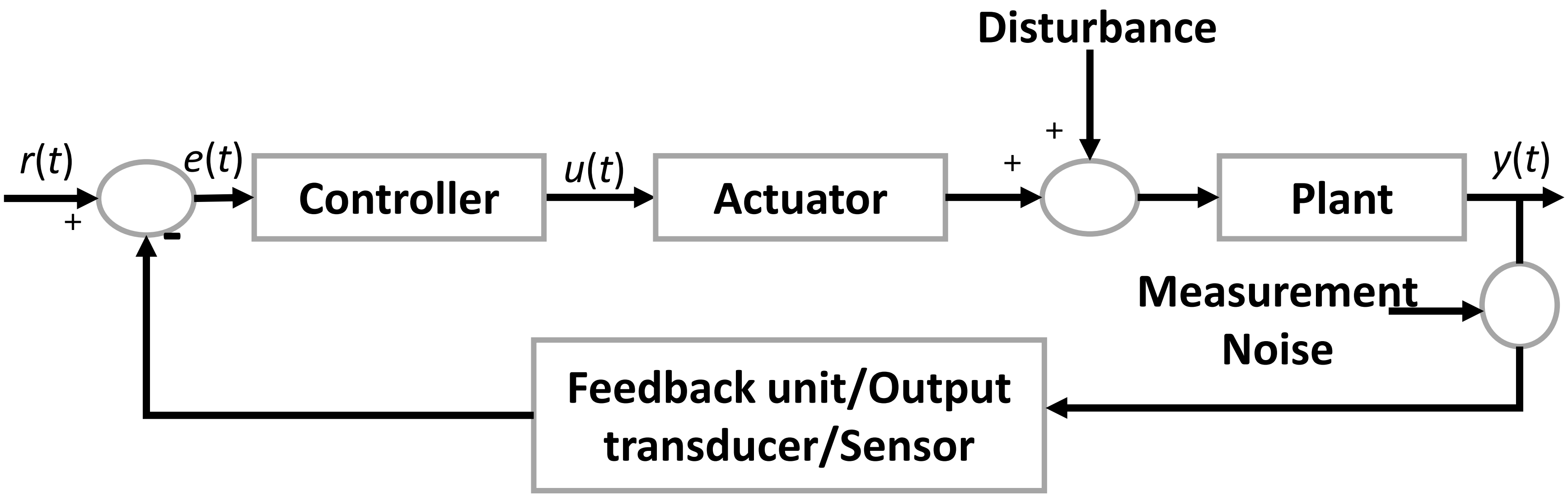


Typical Components of a Feedback Control System



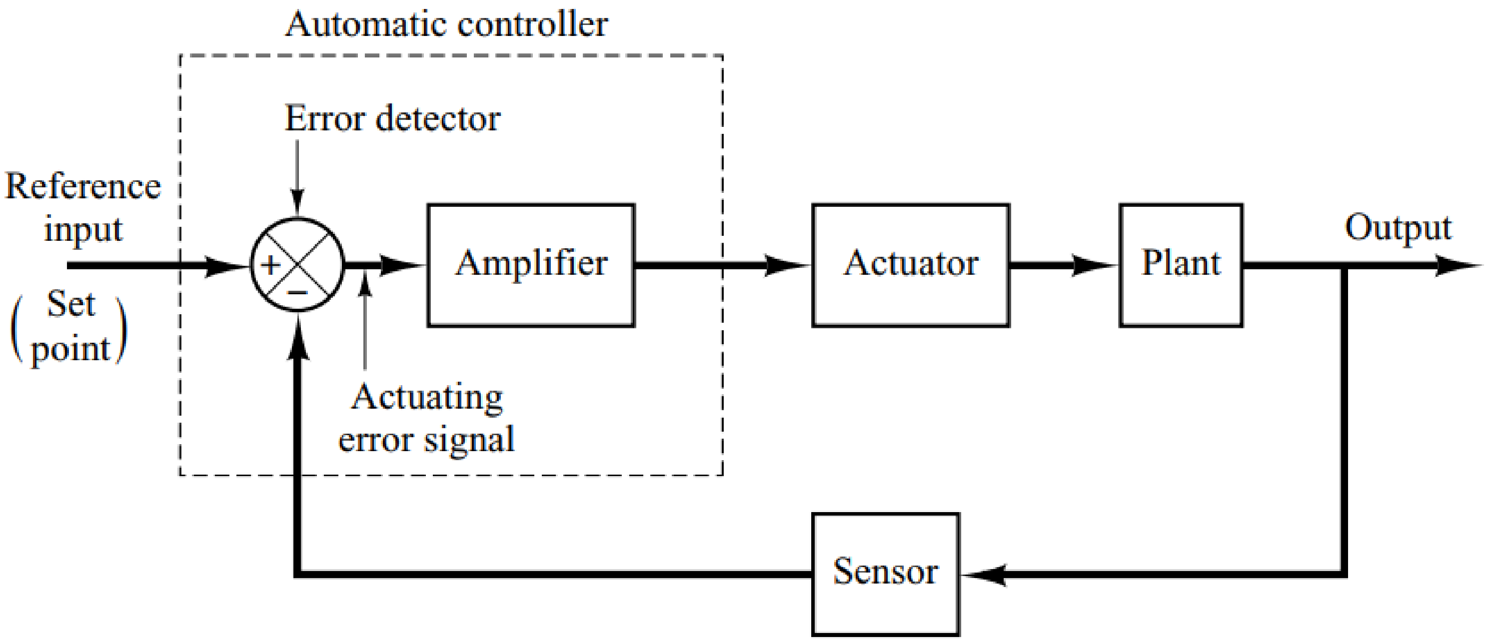
- $r(t)$ – Reference input $u(t)$ – Control input $y(t)$ - Controlled output
- $e(t)$ – Error signal: algebraic sum of the reference input and the feedback signal, which is fed to the controller
- Actuator – A device that produces an appropriate actuating signal that causes the necessary changes in the control variable
- Feedback unit – An output transducer that converts the control output into a proper form of feedback signal

Typical Components of a Feedback Control System with External Disturbance and Measurement Noise



Automatic Control Systems

- The feedback automatically corrects the changes in the output due to disturbance
- An automatic controller compares the actual value of the plant output with the reference input (desired value), determines the deviation, and produces a control signal that will reduce the deviation to zero or to a small value.
- The manner in which the automatic controller produces the control signal is called the *control action*.



Block diagram of an industrial control system

Open loop Vs. Closed-loop Control System

Open loop Control Systems

Advantages

- Simple construction and ease of maintenance
- Less expensive than a corresponding closed loop system
- No stability problem
- Convenient when output is hard to measure or measuring the output precisely is economically not feasible

Disadvantages

- Disturbances and changes in calibration cause errors and output may be different from what is desired
- To maintain the required quality in the output, recalibration is necessary from time to time

Closed loop Control Systems

Advantages

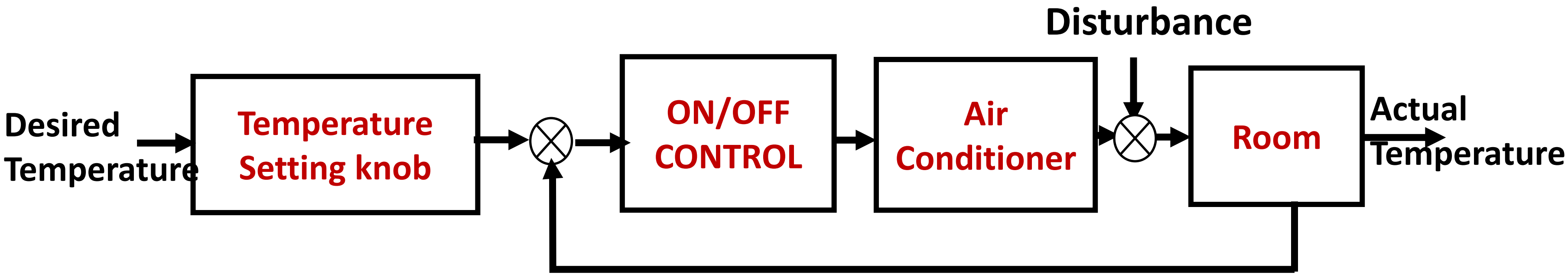
- Use of feedback makes the system response relatively insensitive to external disturbances and internal variations in system parameters
- Relatively less accurate and inexpensive components may be used to obtain the accurate control of a given plan
- Transient response of the system can be improved
- Steady-state error can be reduced

Disadvantages

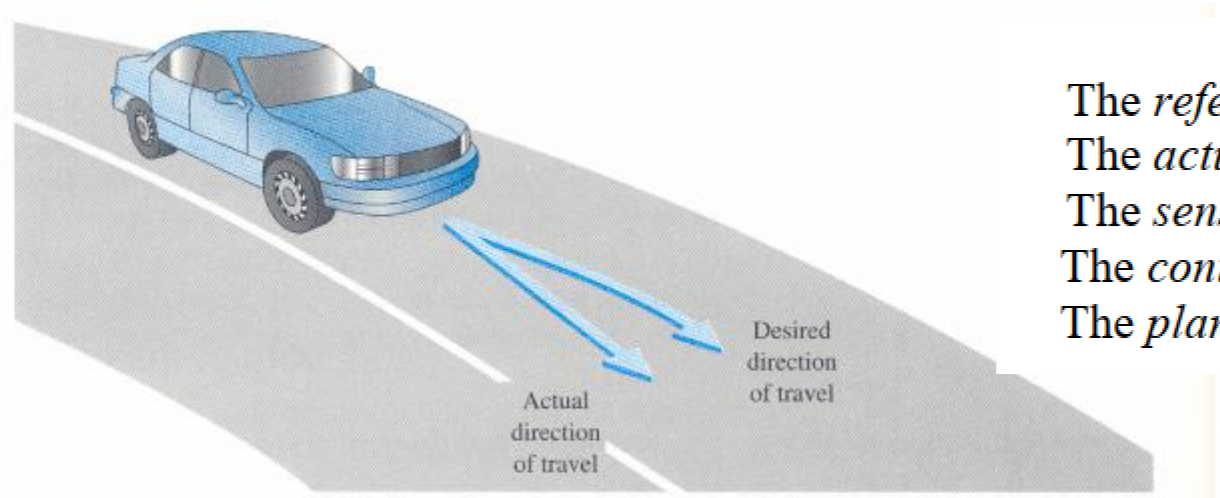
- Tendency to overcorrect error which may create oscillations in the system output. This may cause the system to drift to instability
- Higher in cost and power compared to open loop systems

Examples of Control Systems

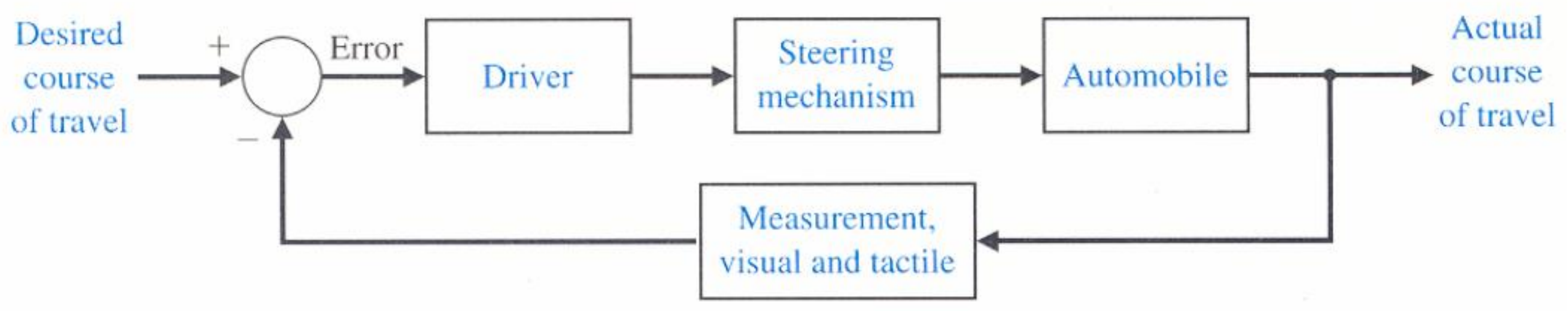
- Air conditioner maintaining the desired temperature



Steering Control Systems



The *reference* is the desired path.
The *actuator* is the steering mechanism.
The *sensor* is the visual.
The *controller* is the driver.
The *plant* is the car.



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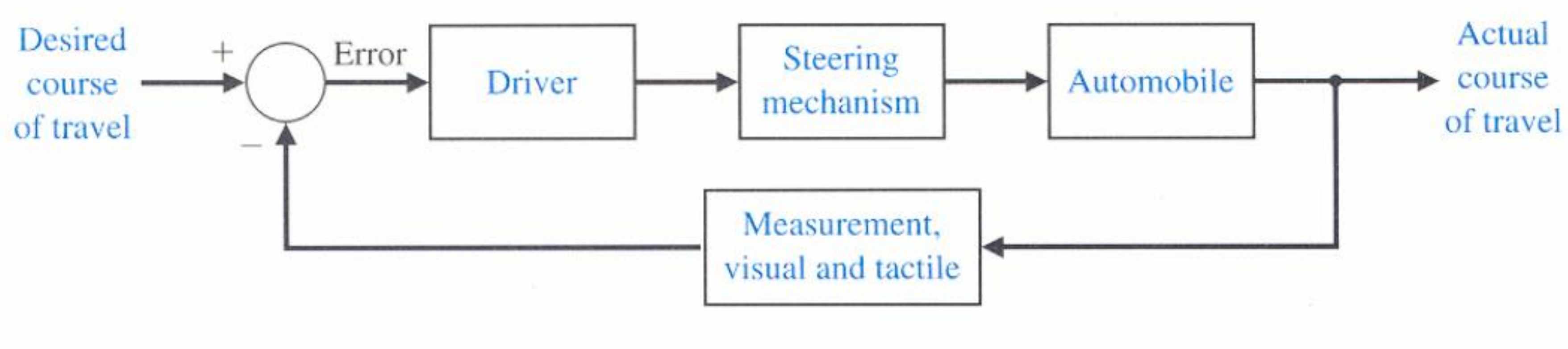
Steering Control Systems



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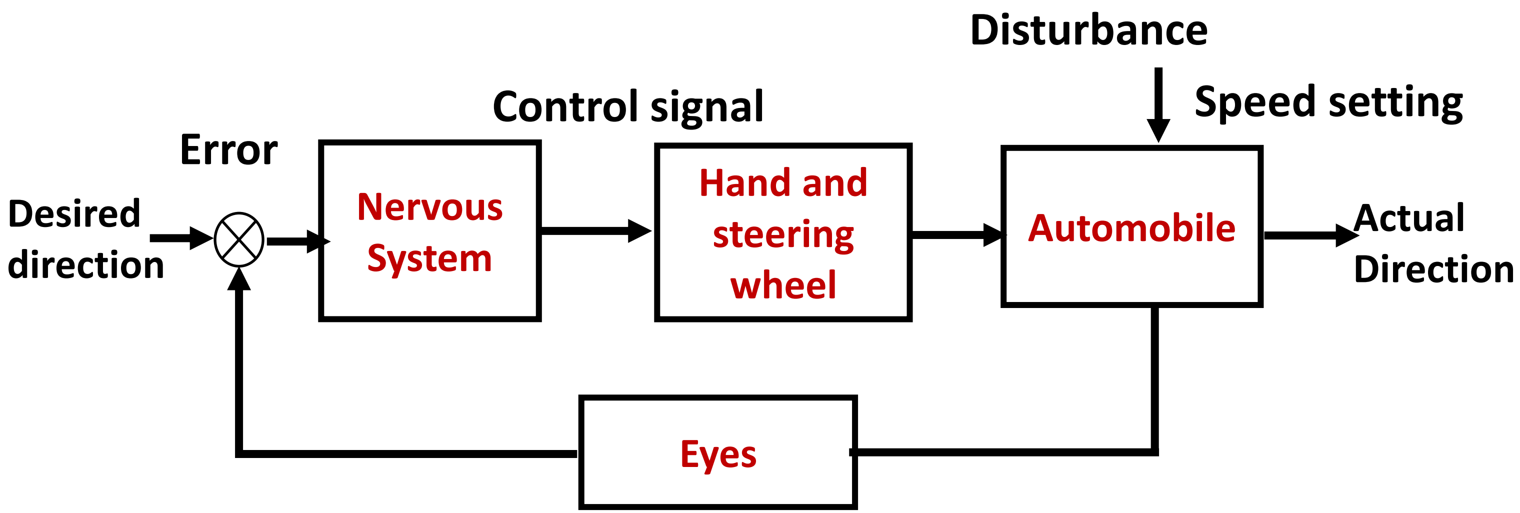
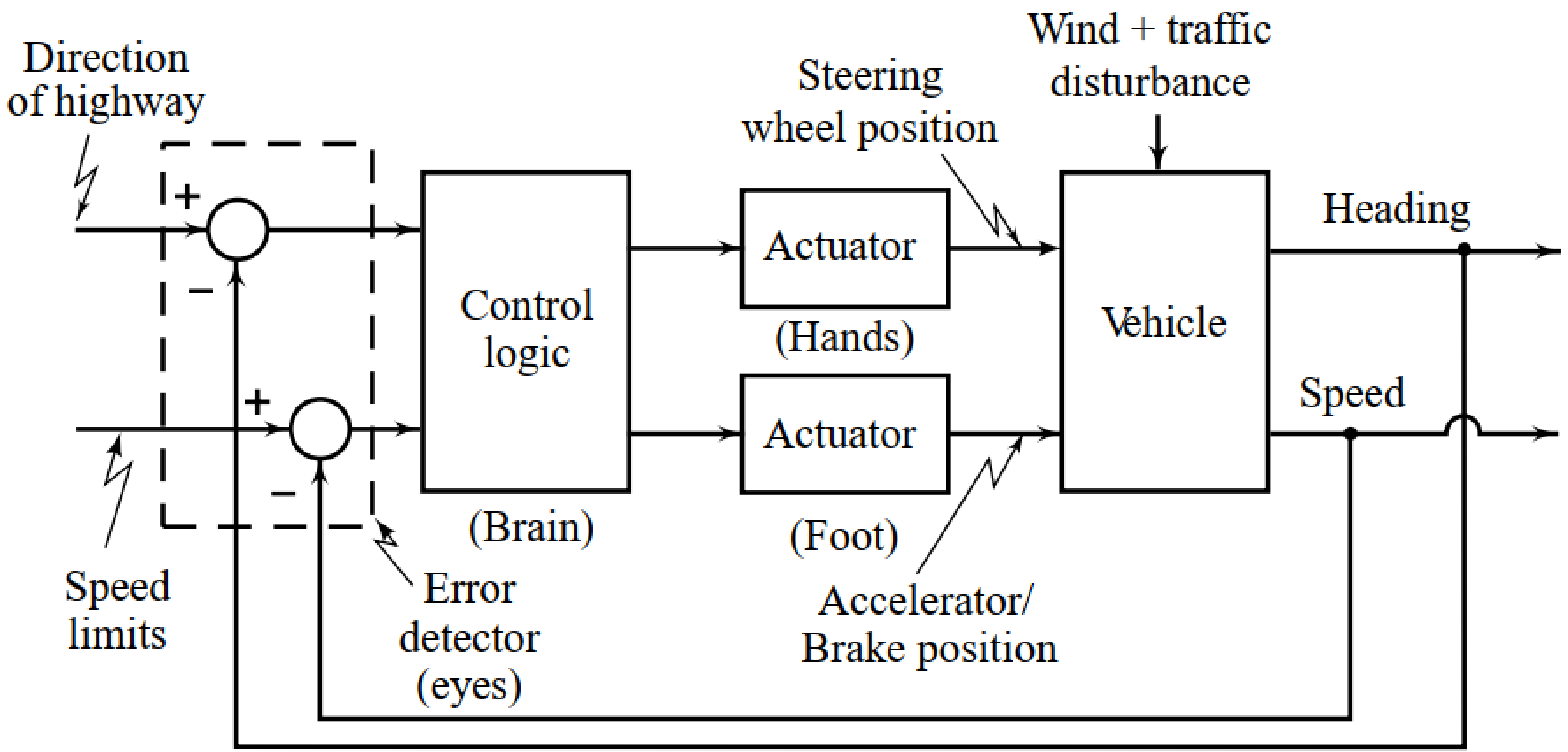
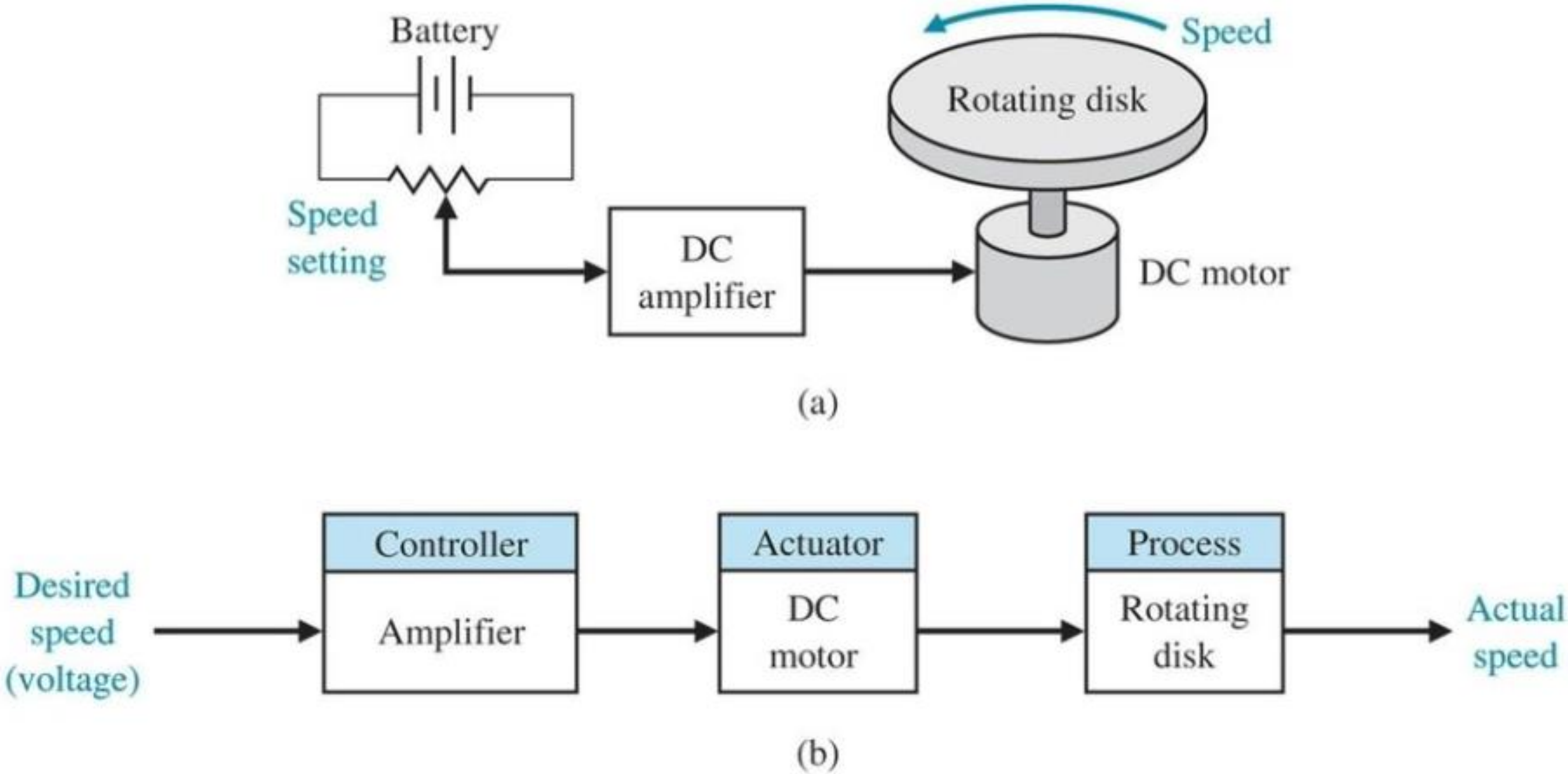


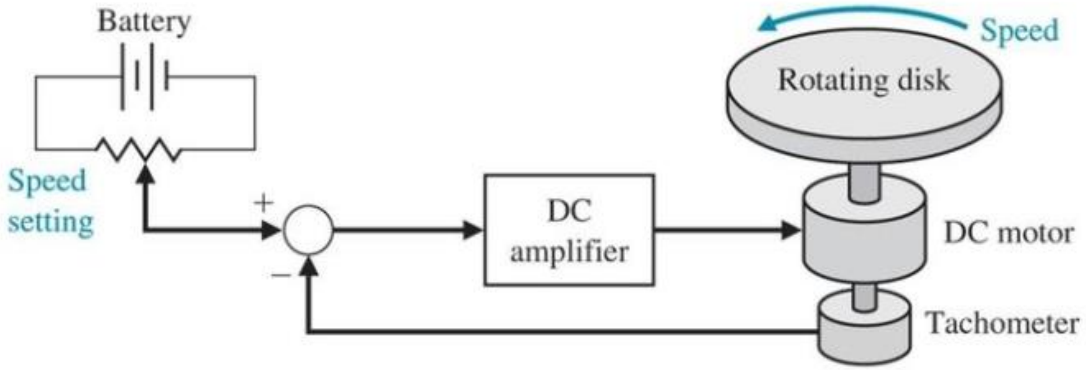
Automobile Driving Control Systems



Open-Loop Speed Control of Rotating Disk



Closed-Loop Speed Control of Rotating Disk



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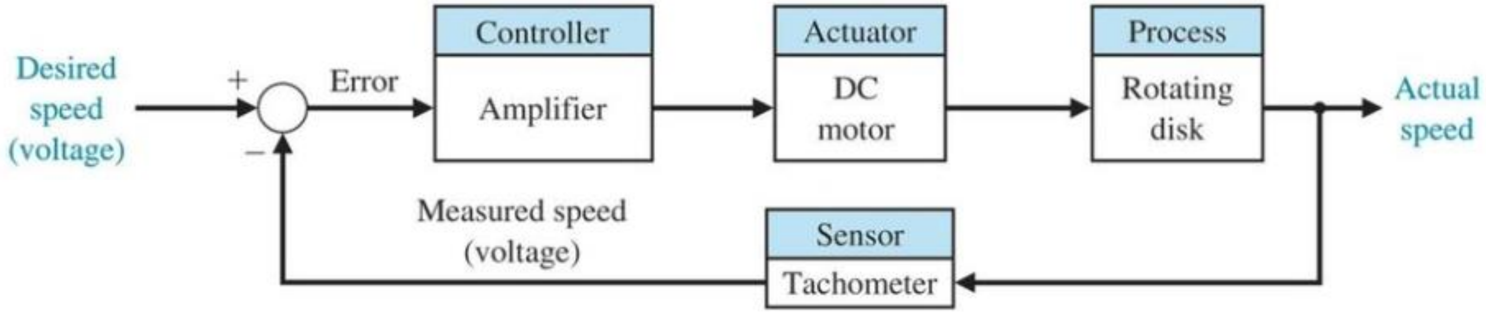
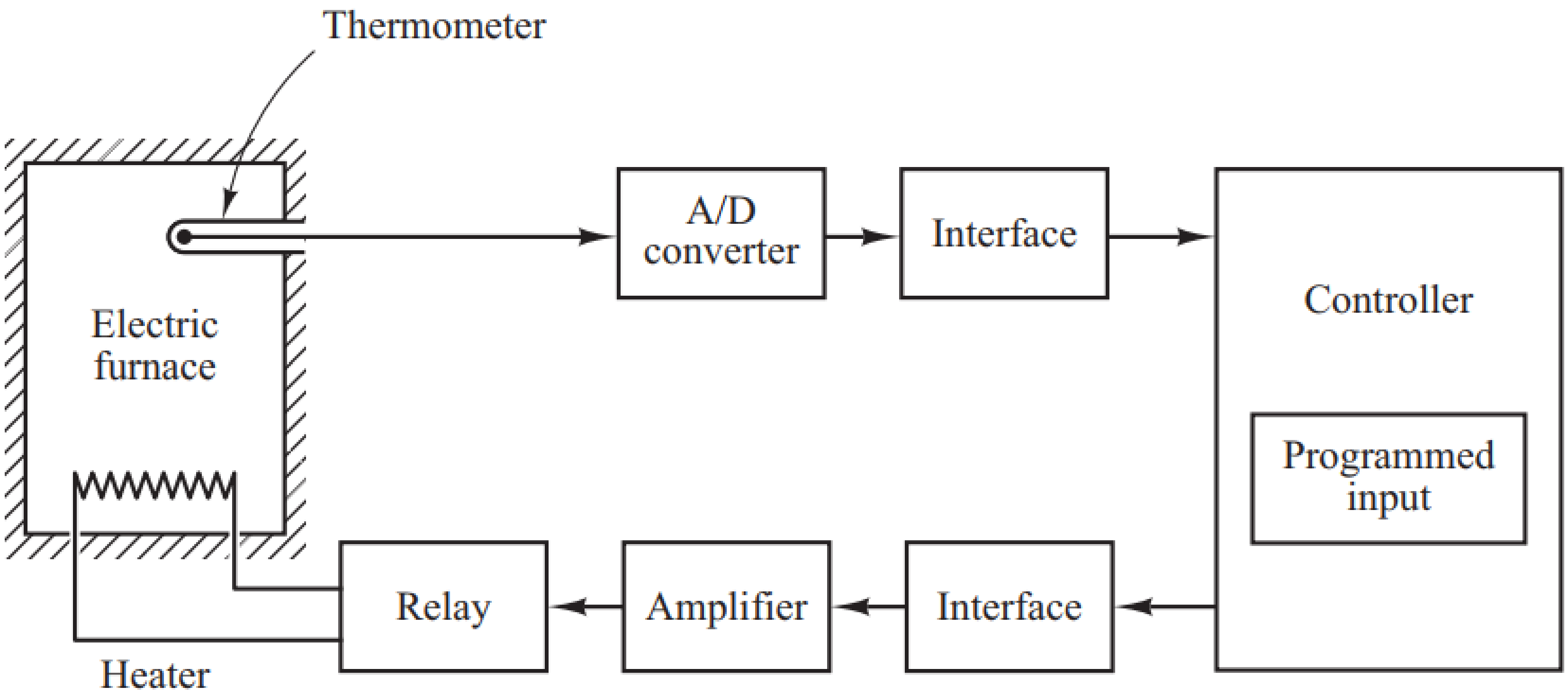
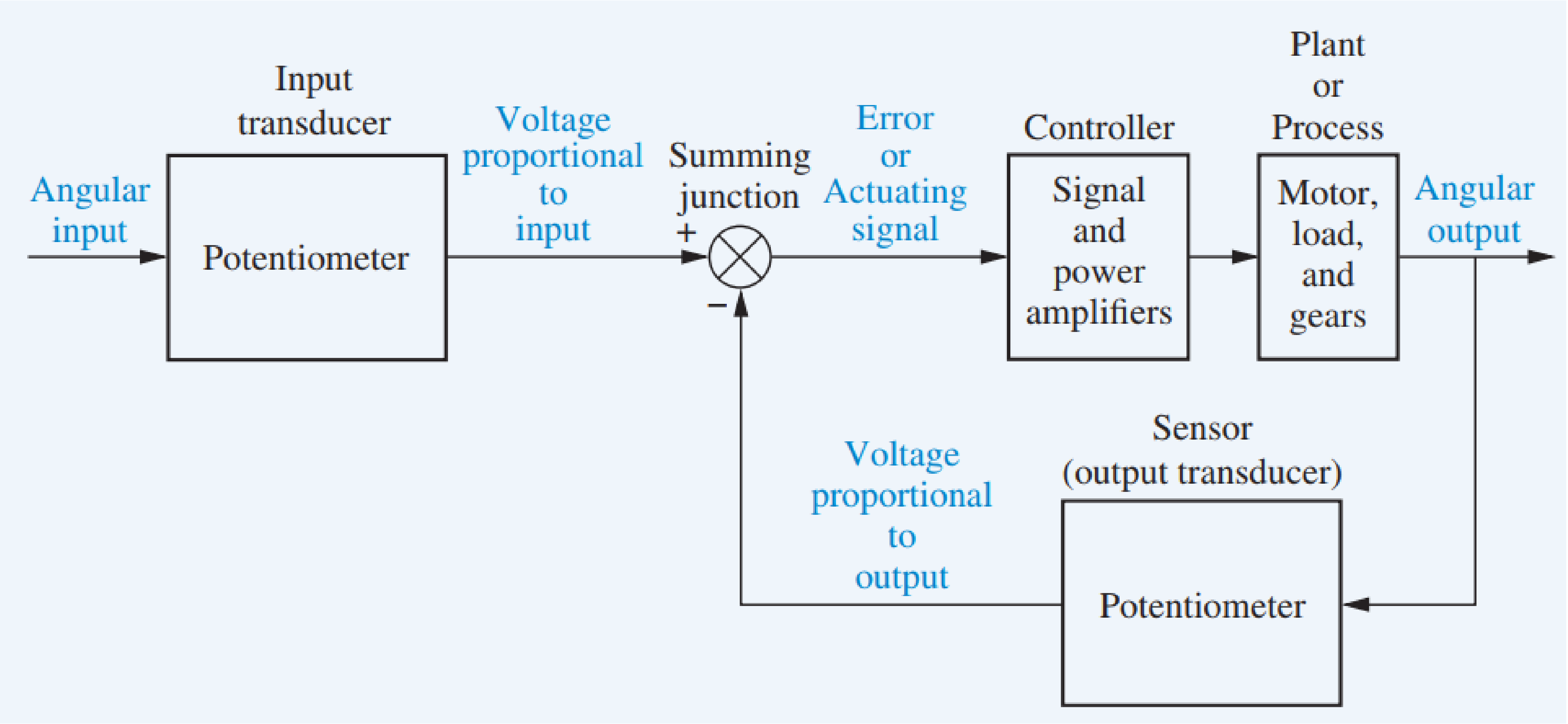


Temperature Control Systems



Antenna Position Control Systems



Engineering Organizational System