Control Systems

EE3302

Chapter 1

An Introduction

Textbook: Control System Engineering, Norman S. Nise, 6th edition, Wiley

Course Objectives

The objectives of this course are:

- To expose students to some important issues in the analysis and design of control systems.
- To use Software packages in the analysis and design of control systems.

Intended Leaning Outcomes (ILO's)

After completing the course, the students should be able to do the following:

- Derive mathematical models of a variety of electrical and mechanical systems.
- Estimate time response of systems to impulse, step, ramp, and sinusoidal inputs from the transfer function.
- Identify simple systems and dominant response characteristics from time domain step-response data.

Intended Leaning Outcomes (ILO's)

- Work confidently with block diagram and signal flow graph representations of control systems.
- Understand the concept of stability of a dynamic system.
- Draw the pole-zero diagram and the root loci, which are the change in location of the poles as parameters are of a system are varied.

Intended Leaning Outcomes (ILO's)

- Understand the meaning of proportional control, integral control, and derivative control, lag compensation, and lead compensation, and how to use them to achieve desired stability, steady-state error, and frequency response.
- To construct simple feedback circuits using op-amps.

5

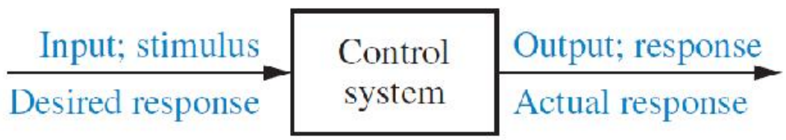
Intended Leaning Outcomes (ILO's)

- Understand the basic structure of a digital control system, including a comprehension of issues such as Nyquist sampling theorem and aliasing as well as structure of Z-transform transfer functions.
- To use Simulation packages with facility to aid in the analysis and design of control systems.

6

What is a Control System?

A Control System consists of subsystems and processes (or plants) assembled to control the outputs of a process.



7

Typical Examples

- Central Temperature Control
- Fluid Level maintenance systems
- Battery Voltage Control
- Human has numerous control systems built in it.

8

Control System another view

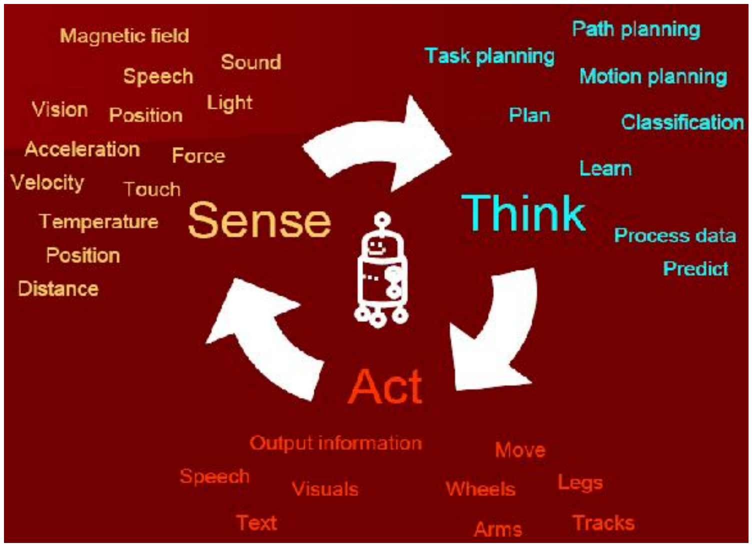
- A Control System is an arrangement of physical components connected/related in such a manner as to command, direct or regulate itself or another system.

9

Human like Control

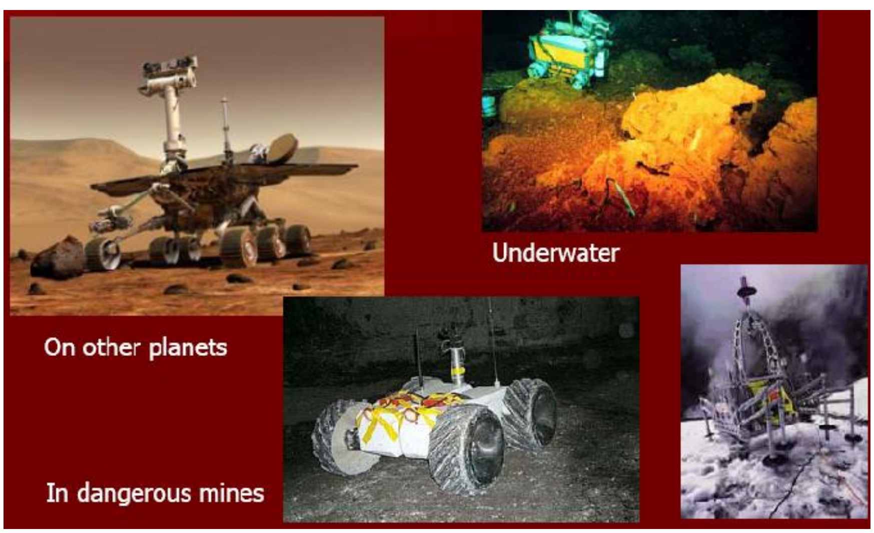
10

How….. Control Systems in Robotics Perspective



11

Autonomous planning and Exploration



12

Industry

……….Everywhere

Control systems are divided into two classes:

a) If the aim is to maintain a physical variable at some fixed value when there are disturbances, this is a *regulator.*

Example: speed-control system on the ac generators of power utility companies.

b) The second class is the *servomechanism.* This is a control system in which a physical variable is required to follow (track) some desired time function.

Example: an automatic aircraft landing system, or a robot arm designed to follow a required path in space.

15

Advantages of a Control System

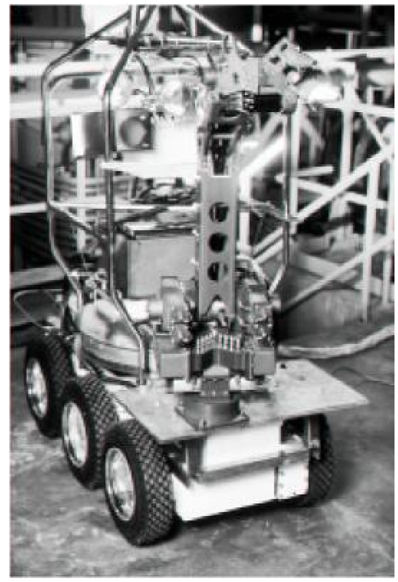
- **Power amplification**
  - Radar antenna positioned by the low-power rotation of a knob at the input, requires a large amount of power for its output rotation. Control system will produce the needed power amplification/power gain.

16

Advantages of a Control System

- **Remote control**

  Rover was built to work in contaminated areas at Three Mile Island where a nuclear accident occurred in 1979.



17

Advantages of a Control System

- **Convenience of input form**
  - In a temperature control system, the input is the position on a thermostat and the output is the heat. Thus a convenient position input yields a desired thermal output.

18

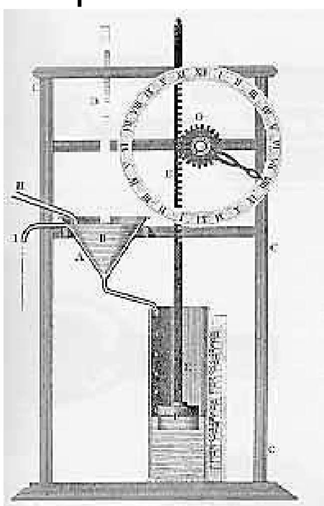
Advantages of a Control System

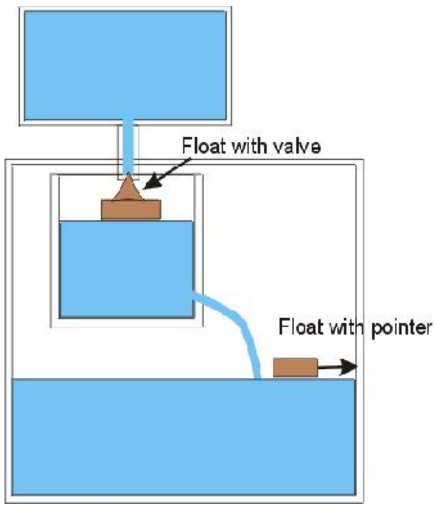
- **Compensation for disturbances**
  – In an antenna system that points in a commanded direction, wind can force the antenna to deviate from commanded direction. The system should detect the disturbance and act accordingly.

19

Classical Control Systems

- Liquid Level Control

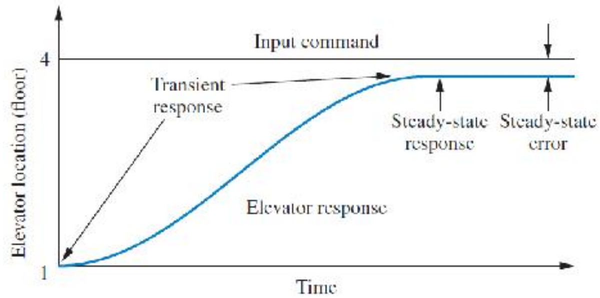




20

Response Characteristics

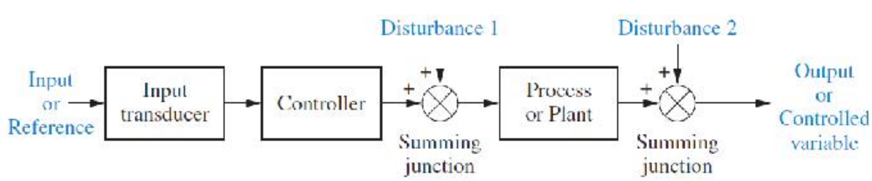
- Consider a control system for an elevator.
  - The input is a step function instructing the elevator to go to a higher floor (4).
  - The output is a transient response plus a steady-state response and has a steady-state error.



21

Open-Loop Systems

- An open-loop system cannot compensate for any disturbances that add to the controller's driving signal or to the process output.



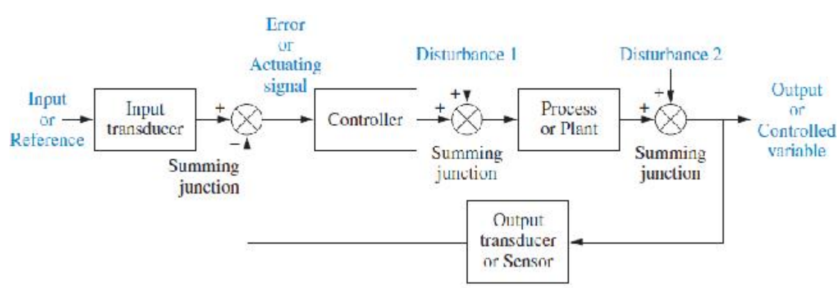
22

Closed-Loop (Feedback Control)

- A closed-loop system can compensate for disturbances by measuring the output, comparing it to the desired output, and driving the difference toward zero.

23

Closed-Loop (Feedback Control)



24

Closed-Loop (Feedback Control)

- Greater accuracy than open-loop systems
- Transient and steady-state responses can be controlled more easily
- More complex and expensive than open-loop systems
  - Requires monitoring the plant output

25

Analysis and Design Objectives

- Transient Response must meet certain criteria. Hard disk read write etc.
- Steady-State Response must meet certain criteria.
- The system must have Stability.
  - Total Response = Natural Response + Forced Response
    - Natural response describes the way the system dissipates or gain energy. It is dependent only on the system not the input
    - Forced response depends on the input.
    - Natural response must go to zero leaving only the forced response or oscillate

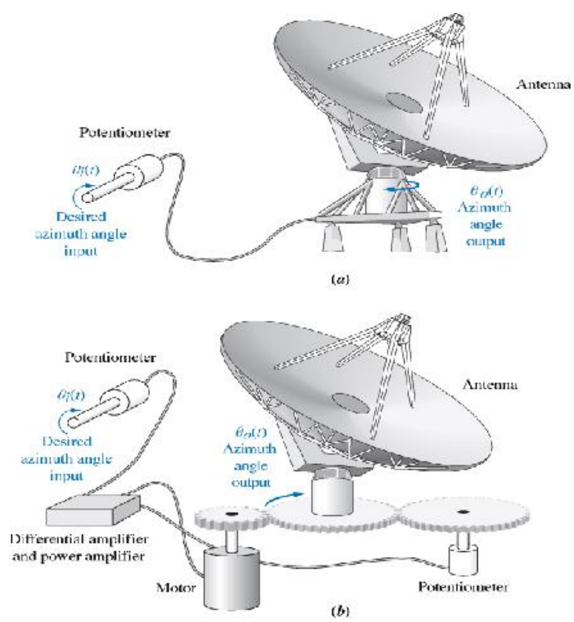
26

Analysis and Design Objectives

- Other Considerations
  - Hardware limitations
  - Finances
  - Robust Design

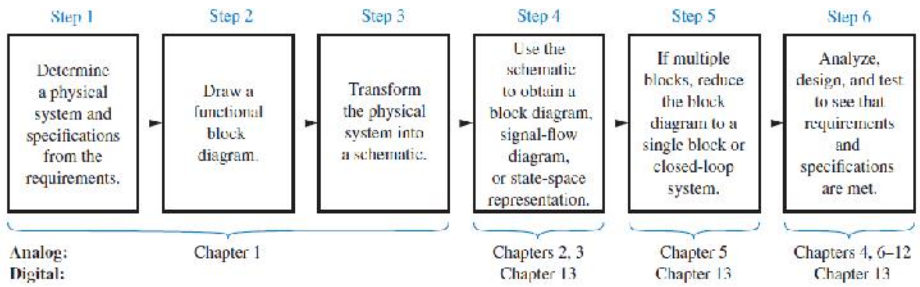
27

Antenna Azimuth Position Control



28

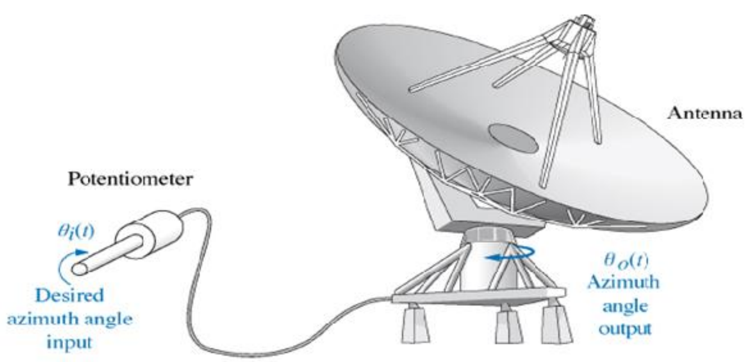
Design Stages for the Antenna



29

Step 1: Transform Requirements into a Physical System

We begin by transforming the requirements into a physical system. For example, in the antenna azimuth position control system, the requirements would state the desire to position the antenna from a remote location and describe such features as weight and physical dimensions. Using the requirements, design specifications, such as desired transient response and steady-state accuracy, are determined.



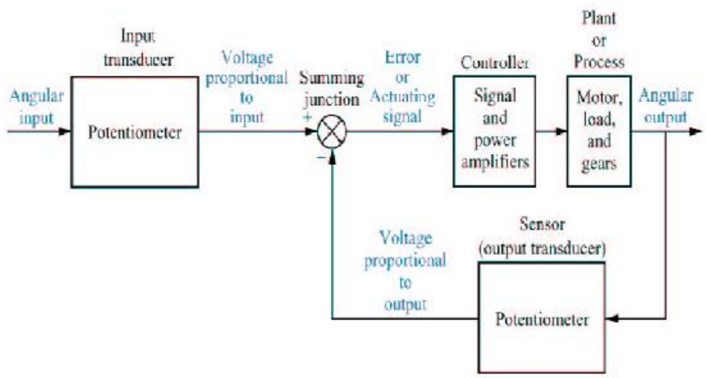
30

Step 2: Draw a Functional Block Diagram

The designer now translates a qualitative description of the system into a functional block diagram that describes the component parts of the system (that is, function and/or hardware) and shows their interconnection.

Antenna Azimuth System

Functional Block Diagram

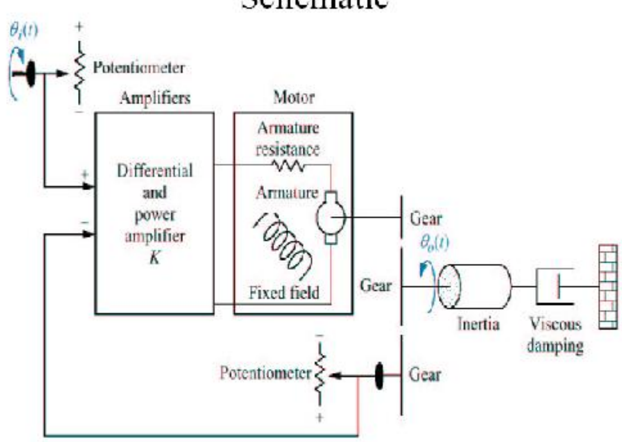


31

Step-3: Draw Schematic

Antenna Azimuth System

Schematic

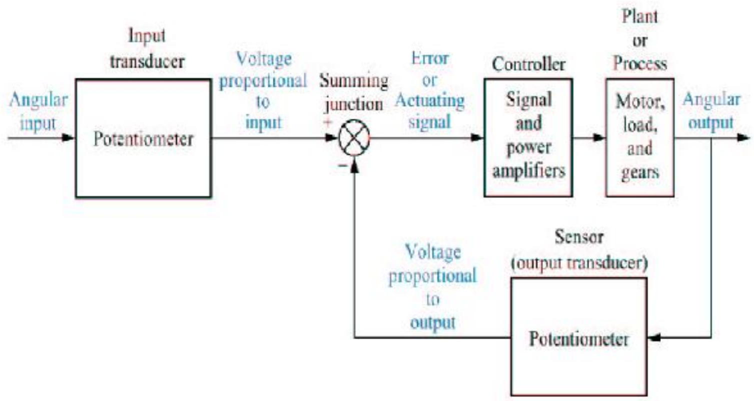


32

Step-4: Draw Block Diagram

Antenna Azimuth System

Functional Block Diagram



33

Mathematical Models

- Model the system mathematically using physical laws.
  - Kirchoff's Voltage Law - The sum of voltages around a closed path is zero.
  - Kirchoff's Current Law - The sum of currents flowing from a node is zero.
  - Newton's Laws - The sum of forces on a body is zero (considering mass times acceleration as a force).

  The sum of moments on a body is zero.
- The model describes the relationship between the input and the output of the dynamic system.

34

$$\frac{d^m c(t)}{dt^m} + a_{n-1}\frac{d^{m-1}c(t)}{dt^{m-1}} + \cdots + a_0 c(t)$$

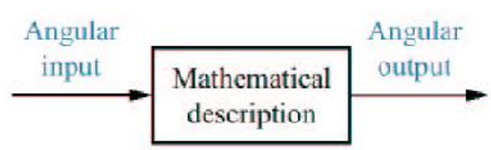
$$= b_m \frac{d^m r(t)}{dt^m} + b_{m-1}\frac{d^{m-1}r(t)}{dt^{m-1}} + \cdots + b_0 r(t)$$

1) Linear, time-invariant differential equation.
2) Transfer function written using the Laplace transform.

35

Step-5: Reduce the Block Diagram

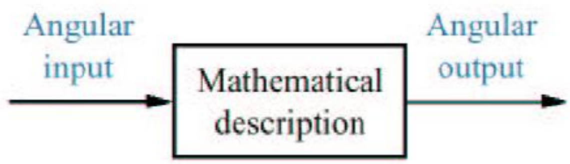
Antenna Azimuth Block Diagram



- The input signal is the desired position of the antenna.
- Several common forms of input functions are used for test purposes.

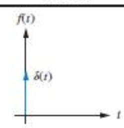
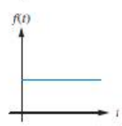
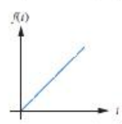
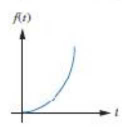
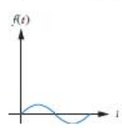
36

Step-6: Analyze and Design



•The input signal is the desired position of the antenna.
•Several common forms of input functions are used for test purposes

TABLE 1.1 Test waveforms used in control systems

Input	Function	Description	Sketch	Use
Impulse	$\delta(t)$	$\delta(t) = \infty$ for $0- < t < 0+$ $= 0$ elsewhere $\int_{0-}^{0+} \delta(t)dt = 1$		Transient response Modeling
Step	$u(t)$	$u(t) = 1$ for $t > 0$ $= 0$ for $t < 0$		Transient response Steady-state error
Ramp	$tu(t)$	$tu(t) = t$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Parabola	$\frac{1}{2}t^2u(t)$	$\frac{1}{2}t^2u(t) = \frac{1}{2}t^2$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Sinusoid	$\sin \omega t$			Transient response Modeling Steady-state error

Why Control Systems?

- *Engineering involves the study of design and analysis of engineering systems.*
- *Engineering systems are physical systems which could be modeled mathematically (mathematical models).*
- *Many engineering or physical systems are control systems.*
  Examples are: central heating system, auto pilot, robots, automobiles, etc.
- *Software engineers often participate in the development of large softwares for control systems, e.g. software for the control of the space shuttle.*

39