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INTRODUCTORY OF SMJE 3153

Your Lecturers

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Universiti Teknologi Malaysia

Assoc. Prof. Dr SEKIGUCHI, Kazuma

(関口 和真)

Advanced Control Systems Lab.

Dept.of Mechanical Systems Engineering

Setagaya Campus

Tokyo City University

Our Class Session

Day/Time	1 8:00-8:50	2 9:00-9:50	3 10:00-10:50	4 11:00-11:50	5 12:00-12:50	6 13:00-13:50	7 14:00-14:50	8 15:00-15:50	9 16:00-16:50	10 17:00-17:50	11 18:00-18:50	12 19:00-19:50	13 20:00-20:50	14 21:00-21:50	15 22:00-22:50	16 23:00-23:50
Monday																
Tuesday																
Wednesday		SMJE3153 (L) SEC 02 **(Lecture)** BILIK KULIAH 13 (06.51.01)					SMJE3153 (L) SEC 01 **(Lecture)** BILIK KULIAH 22 (08.48.01)									
Thursday																
Friday																

ASSESSMENT DETAILS

- Written Test 1 : 20 MARKS
- Written Test 2 : 20 MARKS
- Assignment 1 : 10 MARKS
- FINAL EXAM: 50 MARKS

CLO & PLO

No.	CLO	PLO EAC UTM	Weight (%)	Taxo. & Generic Skills*	T&L Methods	WP	EA	WK	Assessment Methods
CO1	Illustrate the basic principles of automatic control systems.	1 KW	15	C3	Lecture, Active Learning			1	T, F
CO2	Model and analyse time response and stability for electrical, mechanical and electromechanical systems using transfer functions.	2 THPA	45	C4	Lecture, Active Learning			3	T, F
CO3	Design controllers using the Root Locus method.	3 THDS	30	C6	Lecture, Active Learning			5	T, F
CO4	Demonstrate the ability to solve complex engineering control problems by numerical analysis.	5 SCMT	10	P5	Independent learning	1,3,4		6	ASG

Refer *Taxonomies of Learning and **UTM's Graduate Attributes, where applicable for measurement of outcomes achievement
***T – Test; Q – Quiz; ASG –Assignment; PR – Project; Pr – Presentation; F – Final Exam; R-Report; PeeR-Peer Review , Lg- Logbook etc.

Course Structure

Week 1: Course Guidance (Dr Zool)
Week 2: Mathematical Modelling and Time response analysis (Dr Zool)
Week 3: Mathematical Modelling and Time response analysis - Exercise (Dr Zool)
Week 4: Relation to Linearization (Dr Zool)

Week 5: Exact linearization: Theory based on differential geometry (Dr Sekiguchi)
Week 6: Exact linearization: Exercise of symbolic calculation on MATLAB (Dr Sekiguchi)

Week 7: Theory of system stability (Dr Zool)
Week 8: Semester Break

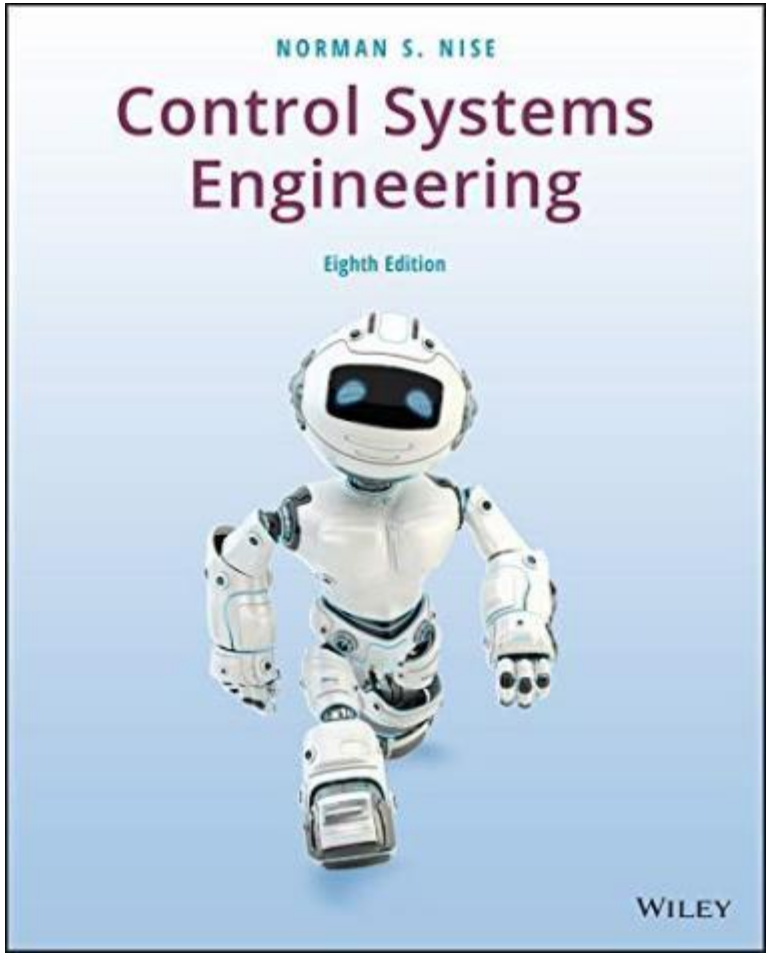
Week 9: Controllability of a control system (Dr Zool)
Week 10 : Controllability of a control system: Exercise (Dr Zool)

Week 11: State feedback controller design (Dr Sekiguchi)
Week 12: Model predictive control: Idea and theoretical solution (Dr Sekiguchi)
Week 13: Model predictive control: Exercise on MATLAB programming (Dr Sekiguchi)

Week 14: Design of advanced controller (Dr Zool)

Week 15: Class summary and revision (Dr Zool)

TEXTBOOK & REFERENCES



- Norman S. Nise, **Control Systems Engineering**, 6th Edition, Wiley, 2011.
- Dean Frederick and Joe Chow, **Feedback Control Problems using MATLAB and the Control System Toolbox**, Thomson, 2000.
- Katsuhiko Ogata, **Modern Control Engineering**, 5th Edition, Prentice Hall, 2010

SYSTEM MODELING & ANALYSIS

CHAPTER 1

Introduction to system

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Content

1.1	• History of Control System **(20 mins.)**
1.2	• Control System Basics **(60 mins.)**
1.3	• Control System Configuration **(30 mins.)**
1.4	• Examples of Control Systems **(20 mins.)**
1.5	• Control System Design **(30 mins.)**
1.6	• Simulation Software in Control – MATLAB **(10 mins.)**

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1.1
HISTORY OF CONTROL SYSTEMS

SHARE YOUR KNOWLEDGE ON CONTROL SYSTEM

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History of Control System

300 BC | **1900's** | **2000's**

Early
- Simple, primitive

- Water clock (300 BC)
- Steam pressure & temperature control systems (1680s)
- Speed control (1745)
- Stability Theories
  - Routh-Hurwitz (1877)
  - Lyapunov (1892)

20th Century
- Extensive use of sensors

- Automatic Ship Steering (1922)
- PID Controller (1920s)
- Feedback Control System Technique (1930s)
- Root locus, Bode, Nyquist (1948)

Contemporary
- Widespread applications

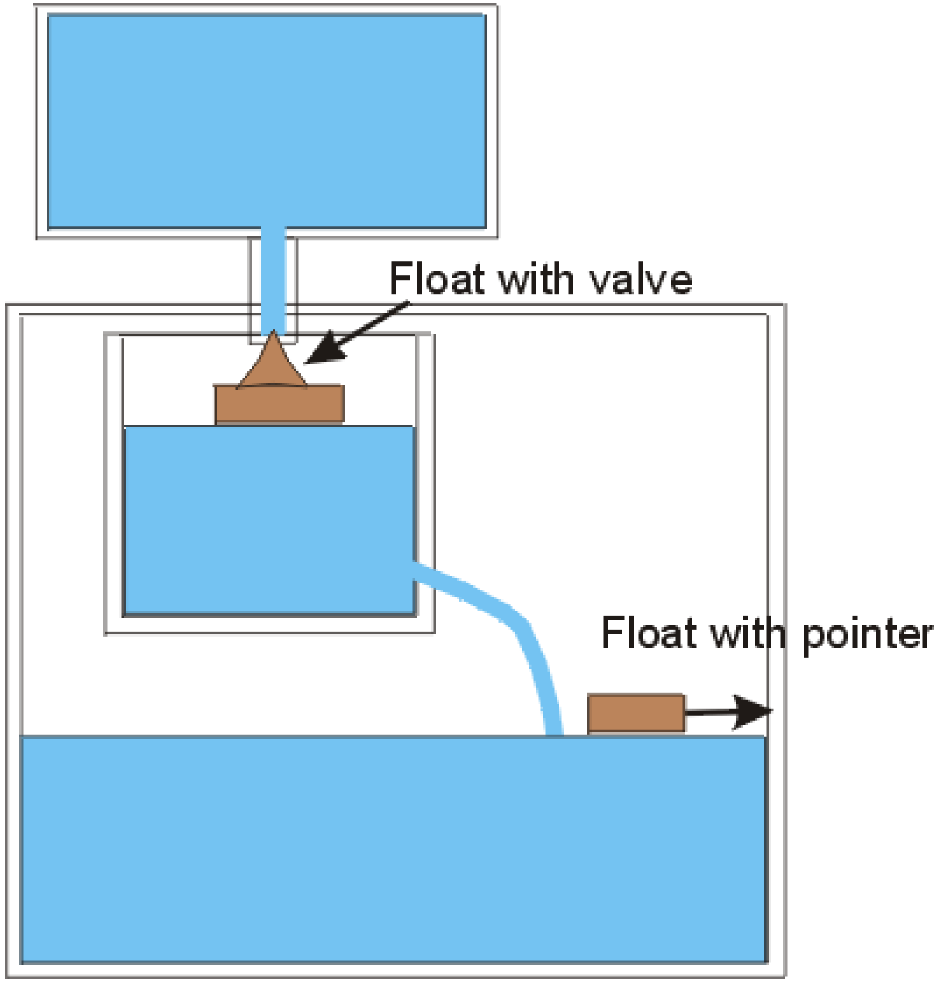
- Navigation
- Entertainment
- Smart Homes
- Military
- Space Application
- Chemical Process

History – Water Clock

One of the earliest control systems known is the water clock invented by Ktesibios (300 BC).

Speed of water flow $\propto$ level of water in an upper tank

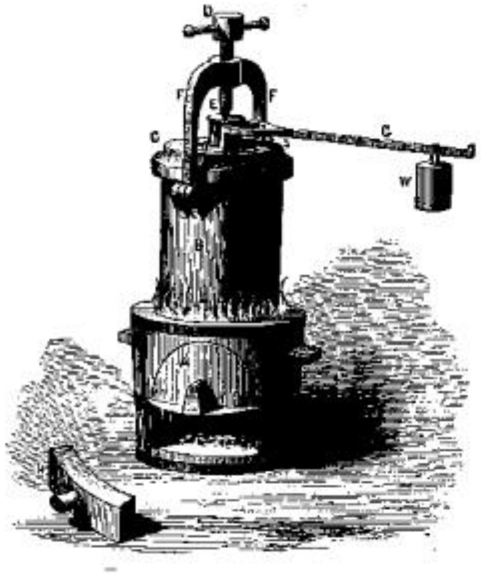
$P=\rho gh$

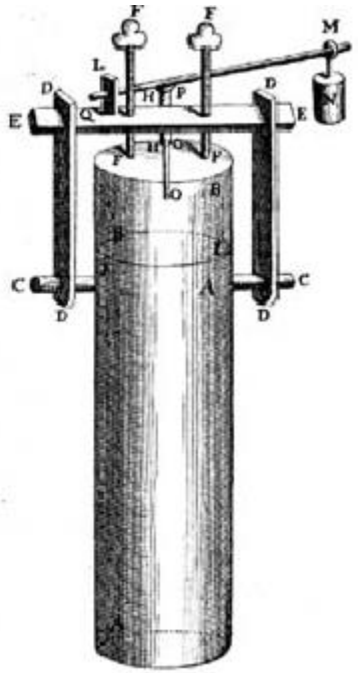


Time scale $\propto$ Level of water of lower tank

History – Steam Pressure Control

In 1681, Denis Papin introduced the steam pressure control systems, where he invented the safety valve (very similar to the present pressure cooker)





History – 20th Century Applications

Contemporary Applications

1.2
CONTROL SYSTEMS BASICS

- General Block Diagram
- Purpose & Methods
- Manual vs. Automatic Control
- Control System Components
- Types of Control Problems

SHARE YOUR KNOWLEDGE ON CONTROL SYSTEM

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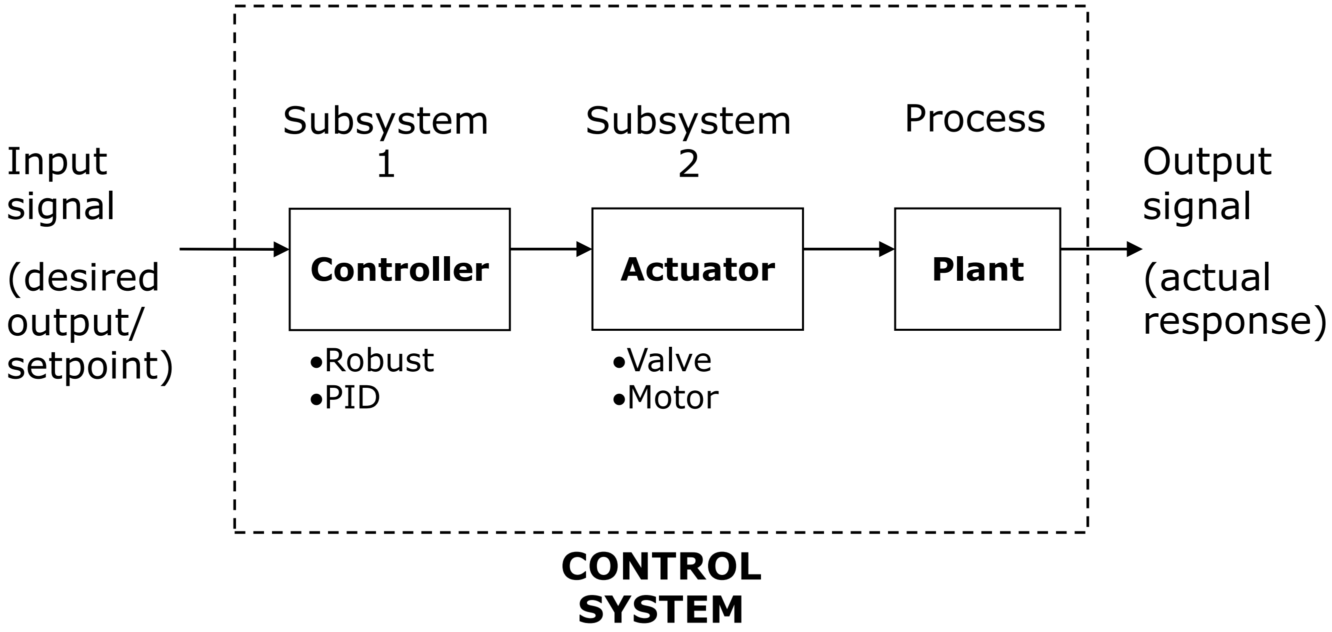
Control System Basics
- General Control System Block Diagram



Control System Basics
- Purpose & Methods

Primary Aim:

- To regulate certain variables about constant values even when there are disturbances.
- To force some parameter to vary in a specific manner.

Control Methods:

- ‘Manual’ control
- ‘Automatic’ control

4 main control purposes

1

- **For power amplification**
- e.g. in moving the radar antenna position to certain angle, small input power is amplified to produce high output torque

2

- **For remote control**
- e.g. in controlling the movements of robots working in contaminated areas where human presence should be avoided

3

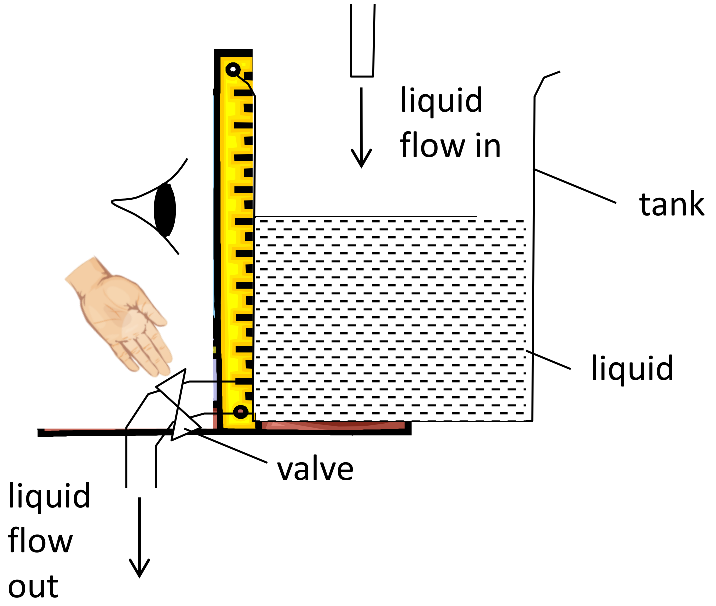
- **For convenience of input form**
- e.g. in a temperature control system, the turn of a knob corresponds to certain desired room temperature.

4

- **For compensation for disturbance**
- e.g. to maintain antenna position in the presence of strong wind.

Manual Control

- Human-aided control
- Operator constantly observe the deviation and make corrections when necessary
- Not consistent
- Hundreds of variables to be controlled



Automatic Control

To replace humans with machines (nowadays, computers) to implement the control of the plant.

- Measurement → sensors/transducers
- Decision → computers
- Control action → actuators

3 Main Control System Components

1. Sensor

- sense the physical signals
- convert into electrical signals
- e.g. thermocouple measures a temperature and converts it into voltage

2. Controller

- the 'brain' of the control system
- does all the calculations and decision-making processes – computer
- compares the desired and actual plant output ➔ calculate the amount of control to be applied

3. Final control element

- accepts an input from the controller, which is then transformed into some proportional operation performed on the process
- must be operated by an actuator
- e.g. to control the yawing direction of a ship, the rudder (the final control element) is moved to certain angle by a hydraulic actuator.

2 Types of Control Problems

Regulation

Problem: CV deviates from SP due to disturbance.

'Regulatory control'

To maintain the quantity at some desired value regardless of external influences.

Servo Control

Problem: CV must follow the changes in the SP.

'Servo Control'

Make CV follow SP when the SP changes.

1.3
CONTROL SYSTEM CONFIGURATION

- Open-Loop & Closed-Loop Systems

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SHARE YOUR KNOWLEDGE ON CONTROL SYSTEM

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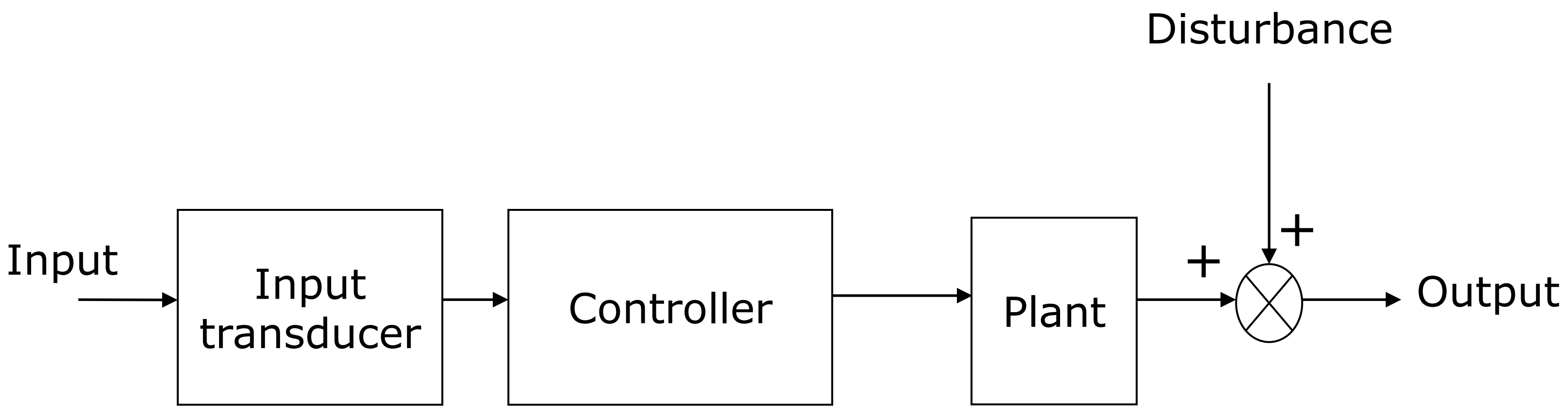
Control System Configuration

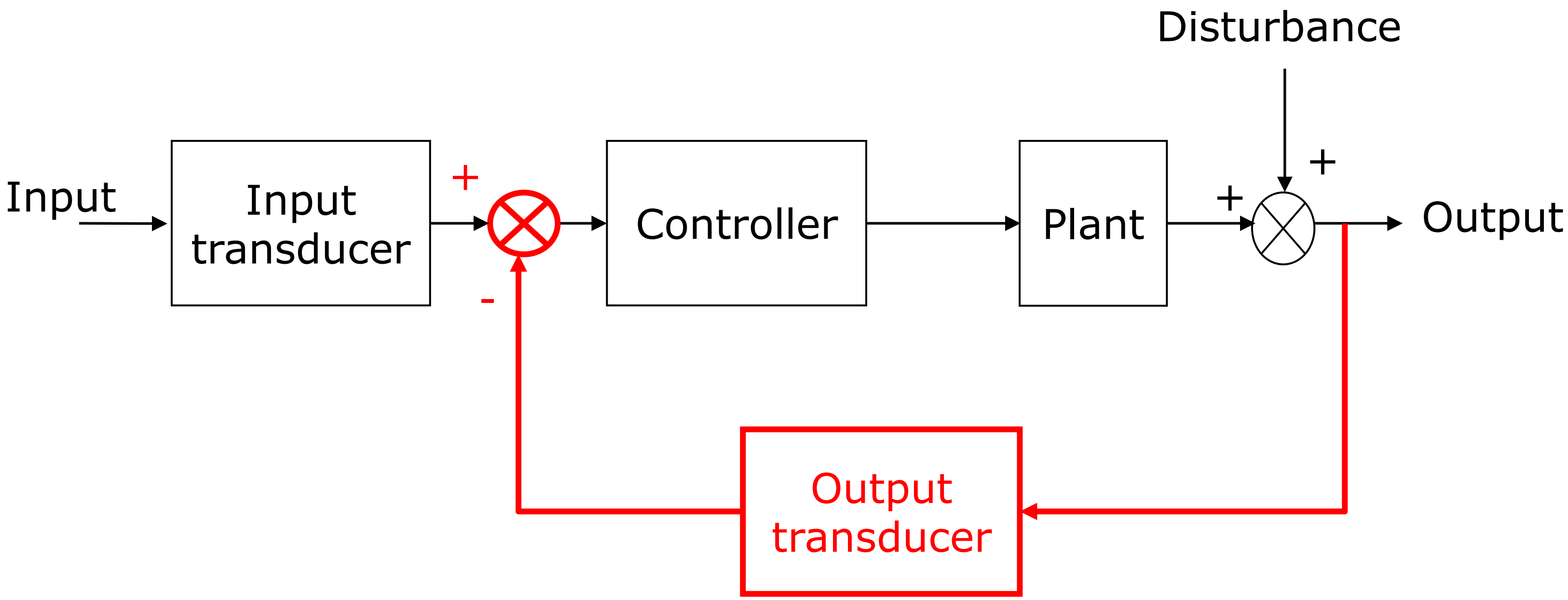
Open-loop

Closed-loop

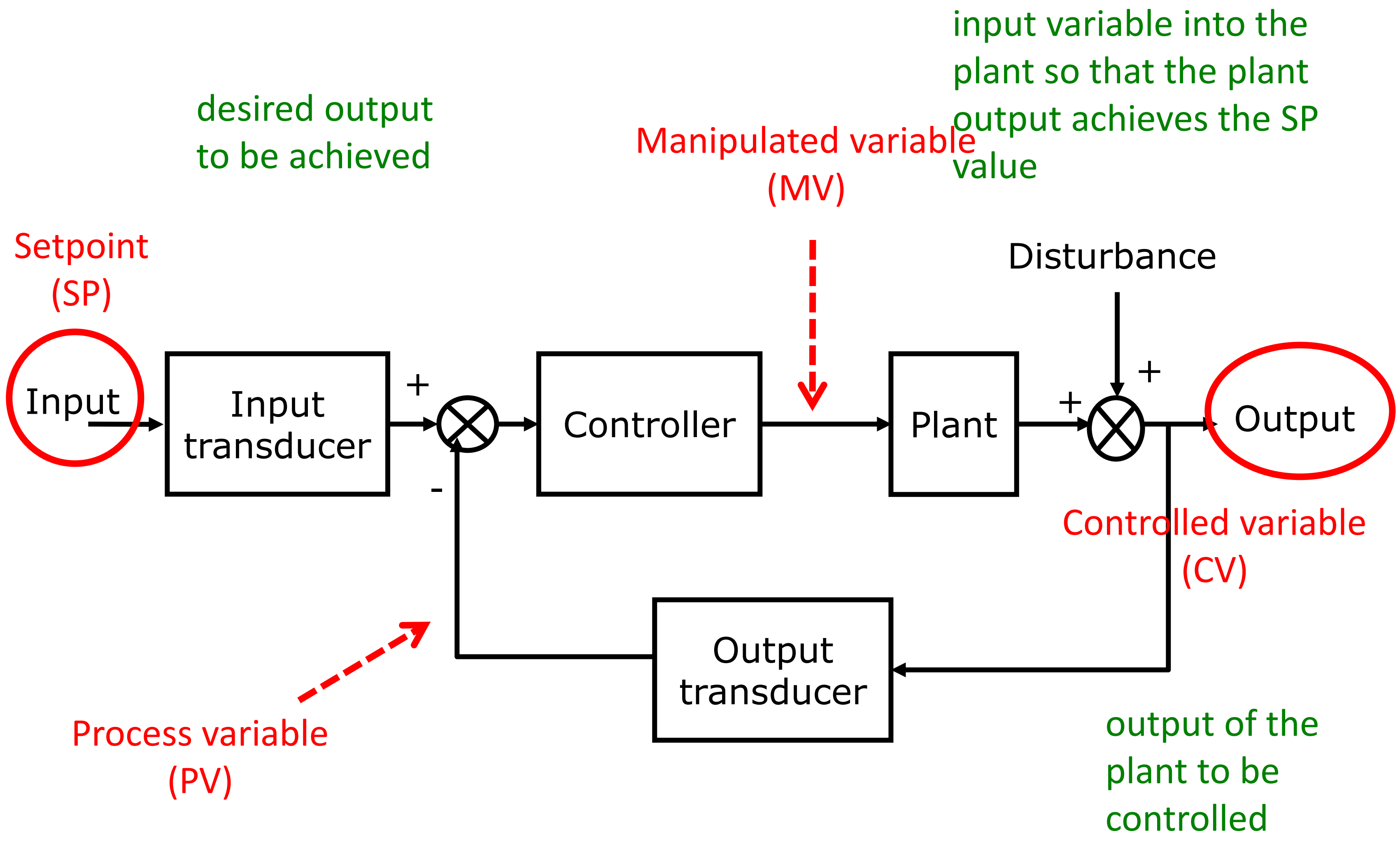
Open-loop Control System



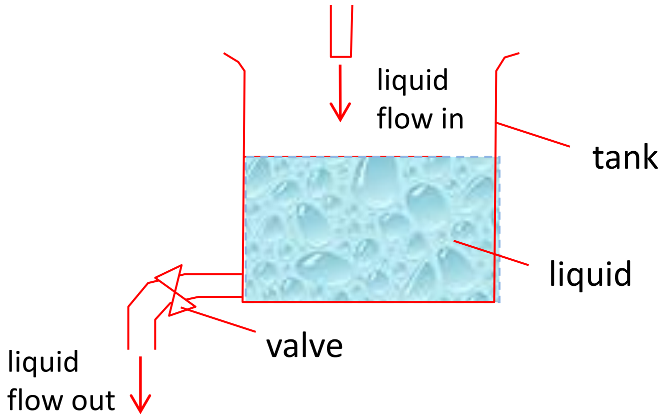
Closed-loop Control System

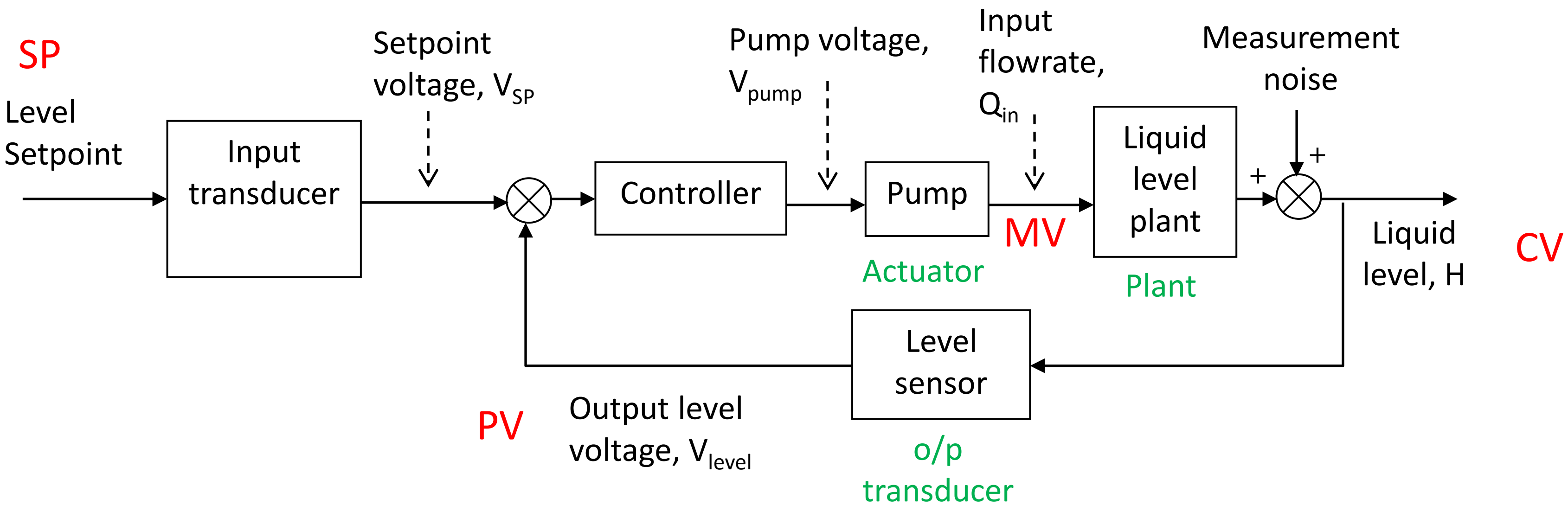


Closed-loop Control System



Example: Liquid Level Control System





1.4
EXAMPLES OF CONTROL SYSTEMS

- Based on System Paradigms
- Based on Types of Signals Used
- Based on System Models
- Based on Control Objectives

Examples

Power amplification in a dish-type antennas

- Varying in diameter from 8 to 30 metres
- Serving an Earth station in a satellite communications network.

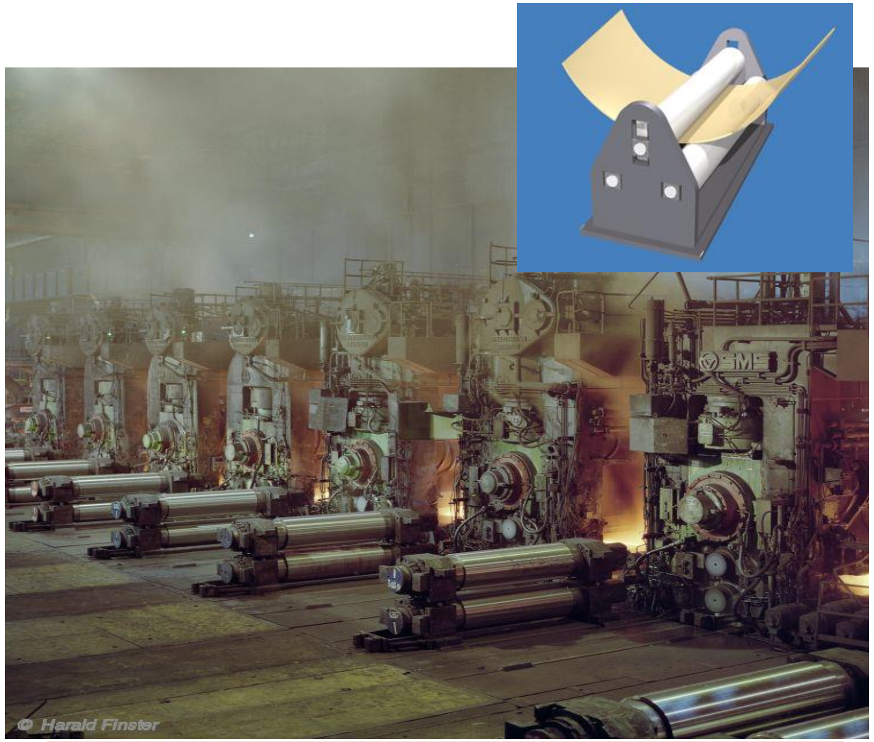
Remote control robots in contaminated area: Sojourner

- Roving on Mars in 1997.
- Solar-powered, 11.5 kg.
- Speed: 0.4 meters/minute
- Its wheel system enabled it to climb over obstacles one-and-a-half wheel diameters tall.

Examples

Convenient input for a **thermostat**

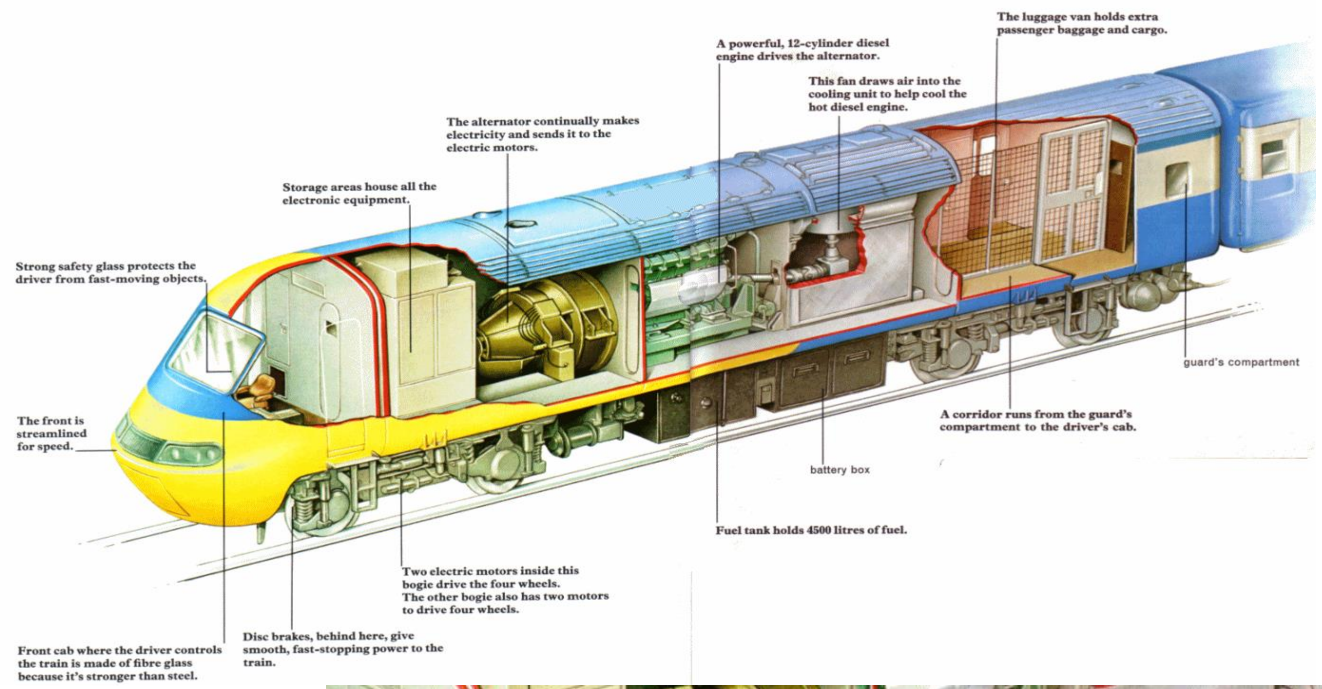
- Position to heat

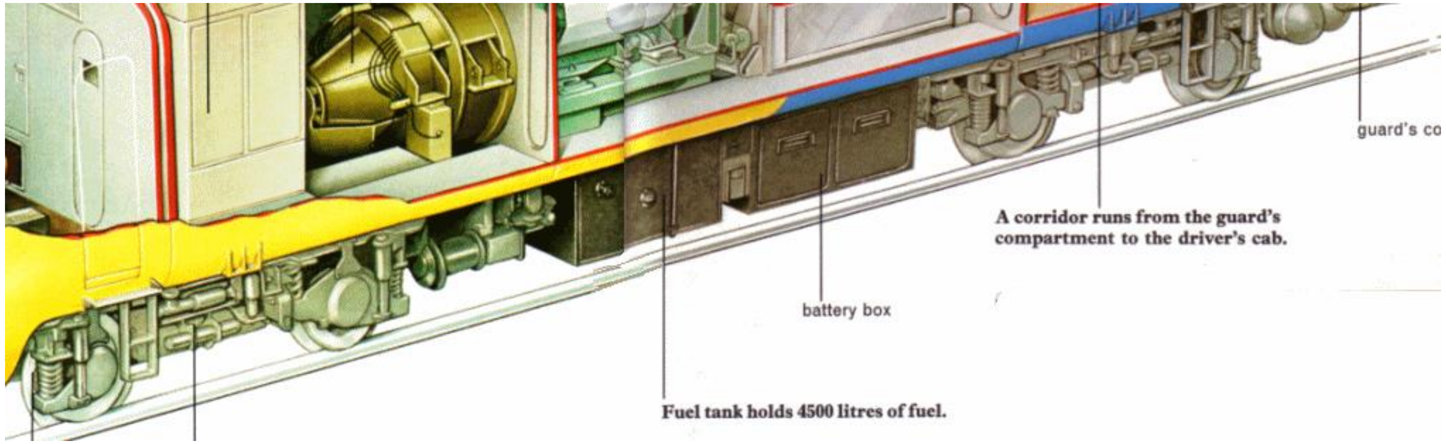


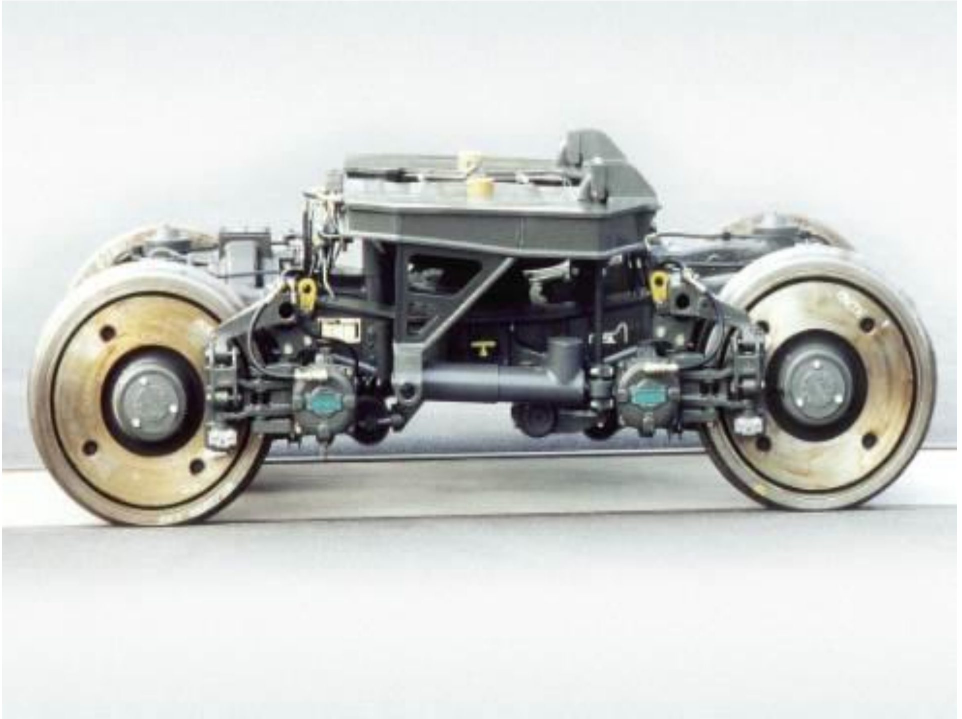
Disturbance compensation in a **Rolling Mill**

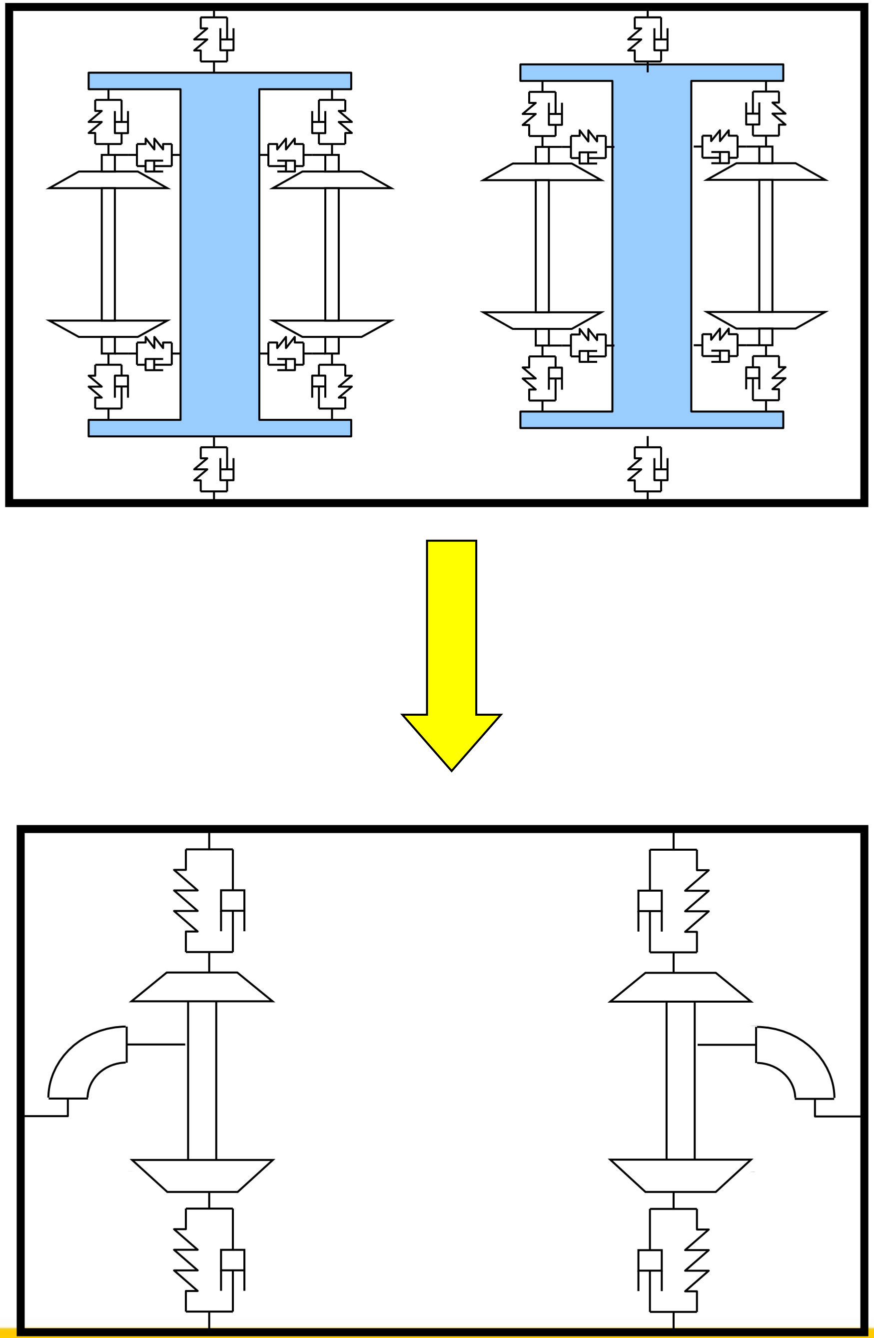
- Maintain steel thickness despite variations/disturbance

Other Example: High-speed Train Suspension System





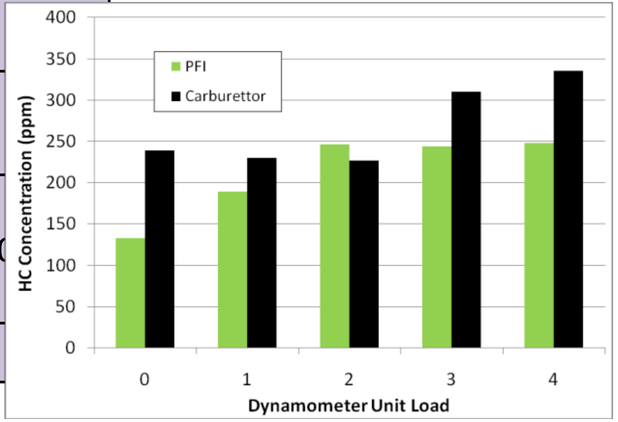




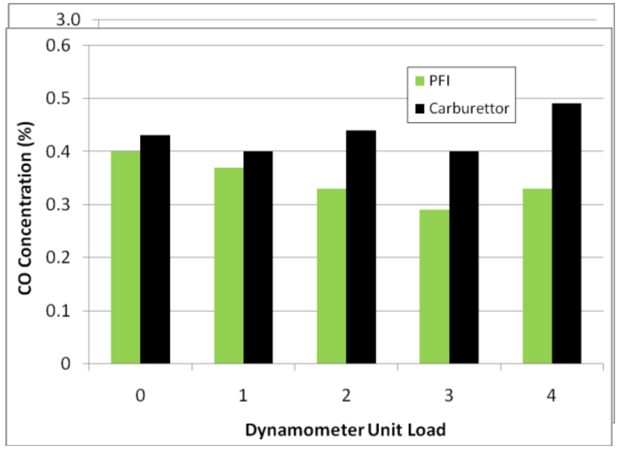
Other Example: Emission Control for Automotive Engines

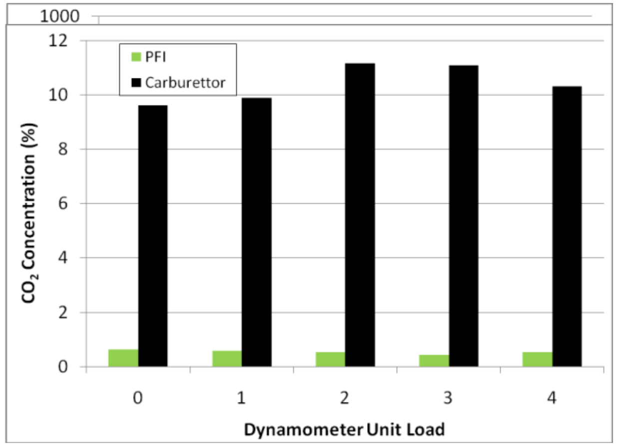
Emission Regulation

Tier	Date	CO	THC	NMHC	NO_x	$HC+NO_x$	PM
Euro 1	October 1994	2.72	-	-	-	0.97	
Euro 2	January 1998	2.2	-	-	-	0.5	
Euro 6	Septembe r 2014	1.000	0.100	0.068	0.060	-	0.0
* Applies only to vehicles with direct injection engines							



Replacing carburetor engines with fuel injection system





Electronic Control
Unit (ECU)

1.5 CONTROL SYSTEM DESIGN PROCESS

Controller Design Process - General

Mathematical modelling

Laws of Physics	System identification

↓

Analysis

Time domain	Frequency domain

↓

Design of controller

Controller structure	Controller type

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Controller Design Process - General

STEP 1
- Transform requirements into physical systems

STEP 2
- Draw a functional block diagram

STEP 3
- Create a schematic

STEP 4
- Develop mathematical model (block diagram)

STEP 5
- Reduce block diagram

STEP 6
- Analyze & Design

Chapter 1 (Steps 1–3)

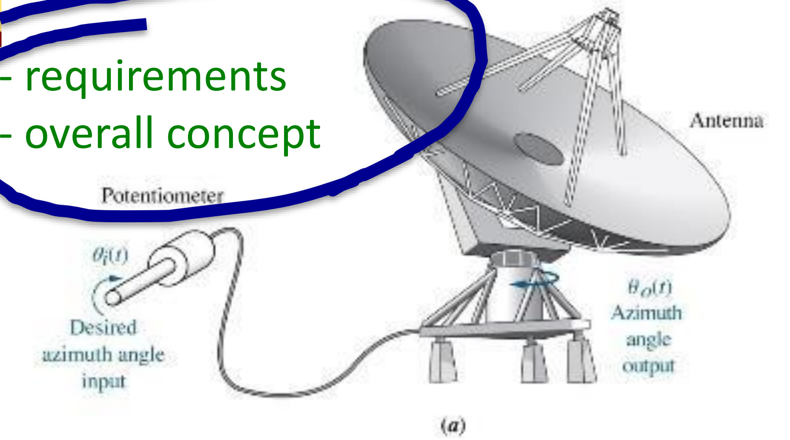
Chapter 2 (Step 4)

Chapter 3 (Step 5)

Chapter 4 (Step 6)

Example – Antenna Position Control

- requirements
- overall concept



Determine a physical system

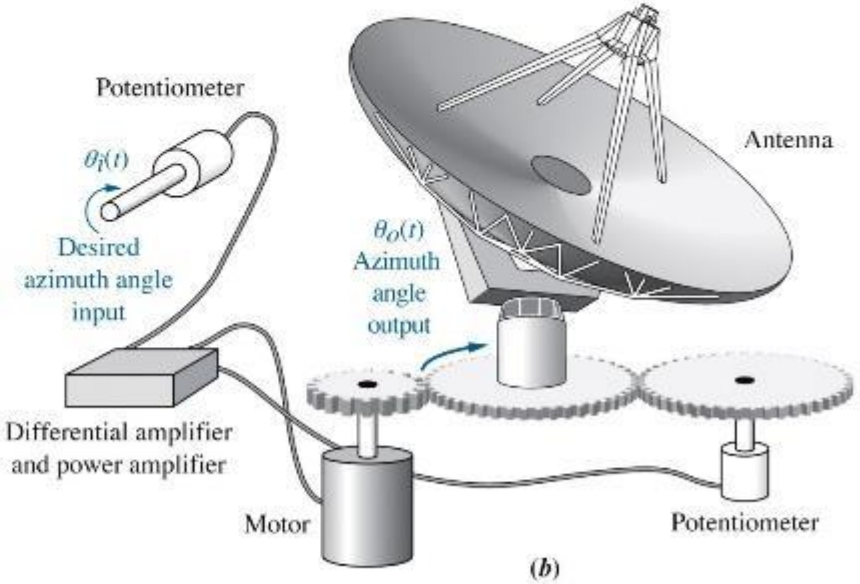
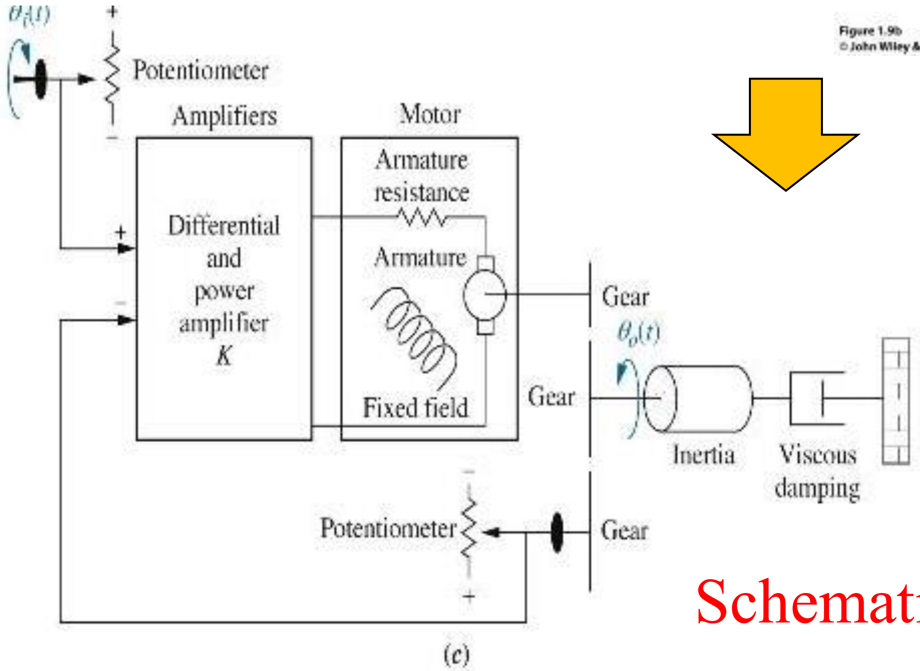


Figure 1.9b

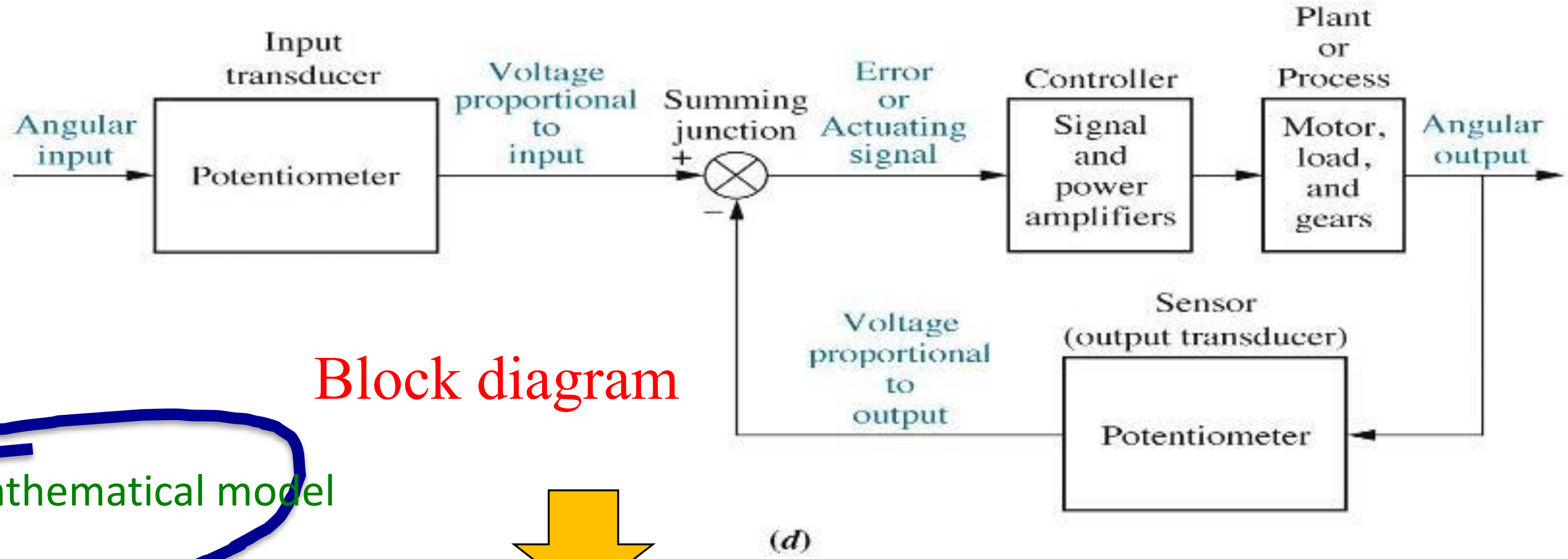
Draw a functional block diagram

- components
- hardware



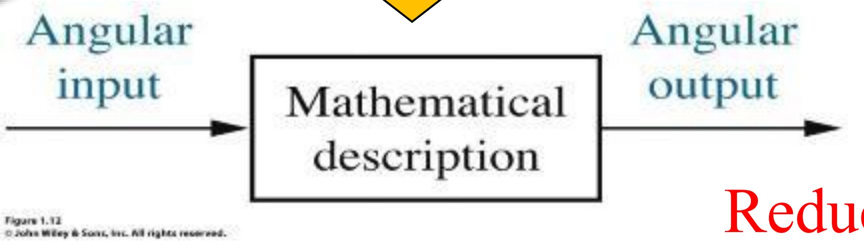
Schematic

- assumptions
- simplifications

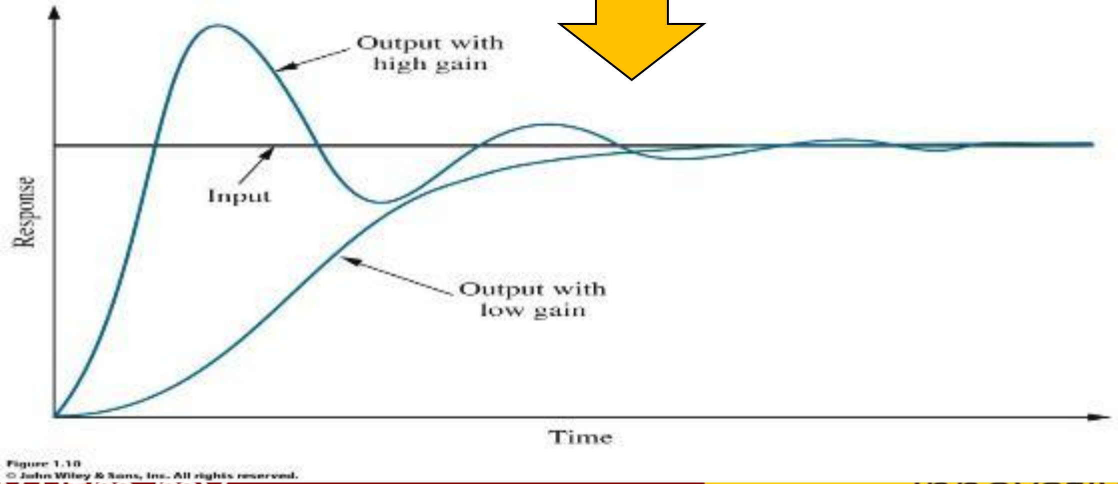


Block diagram

Mathematical model



Reduced block diagram



Analysis

1.6
MATLAB

- MATLAB
- Control System Toolbox
- Simulink

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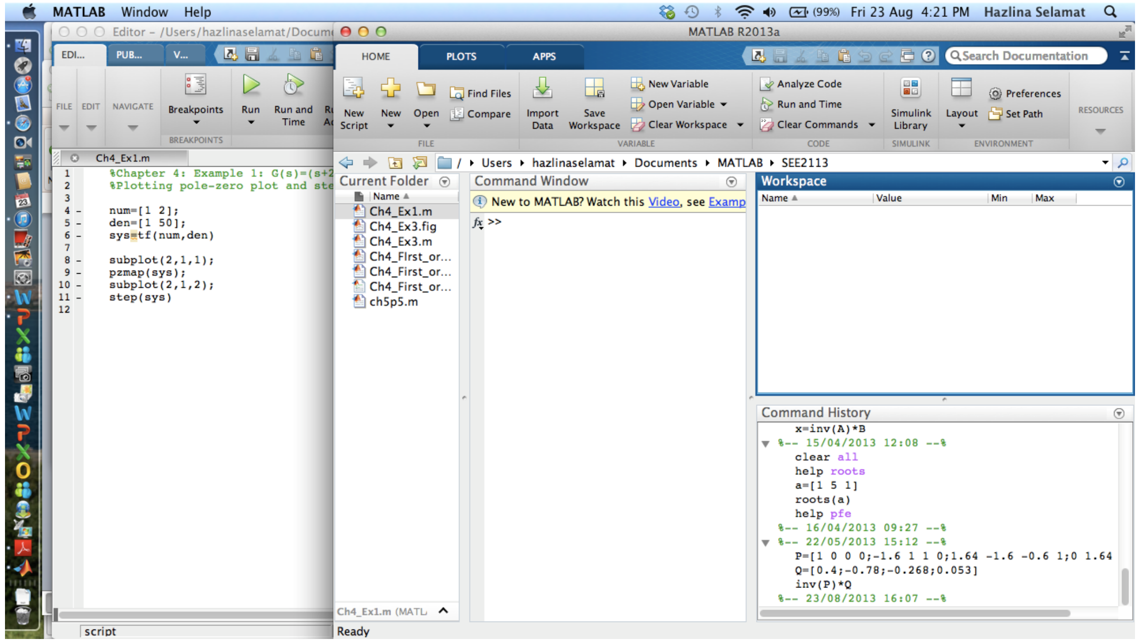
MATLAB

- Important tool in current control system design.
- Recall:
  - To achieve:
    - » **<u>PO4</u>**: Ability to work with modern instrumentation, software and hardware.
  - through:
    - » **<u>CO4</u>**: Apply **MATLAB** software in analyzing control system performance
- MATLAB contains:
  - Lots of Toolboxes – one of them is ‘Control System Toolbox’
  - Simulink – click and drag

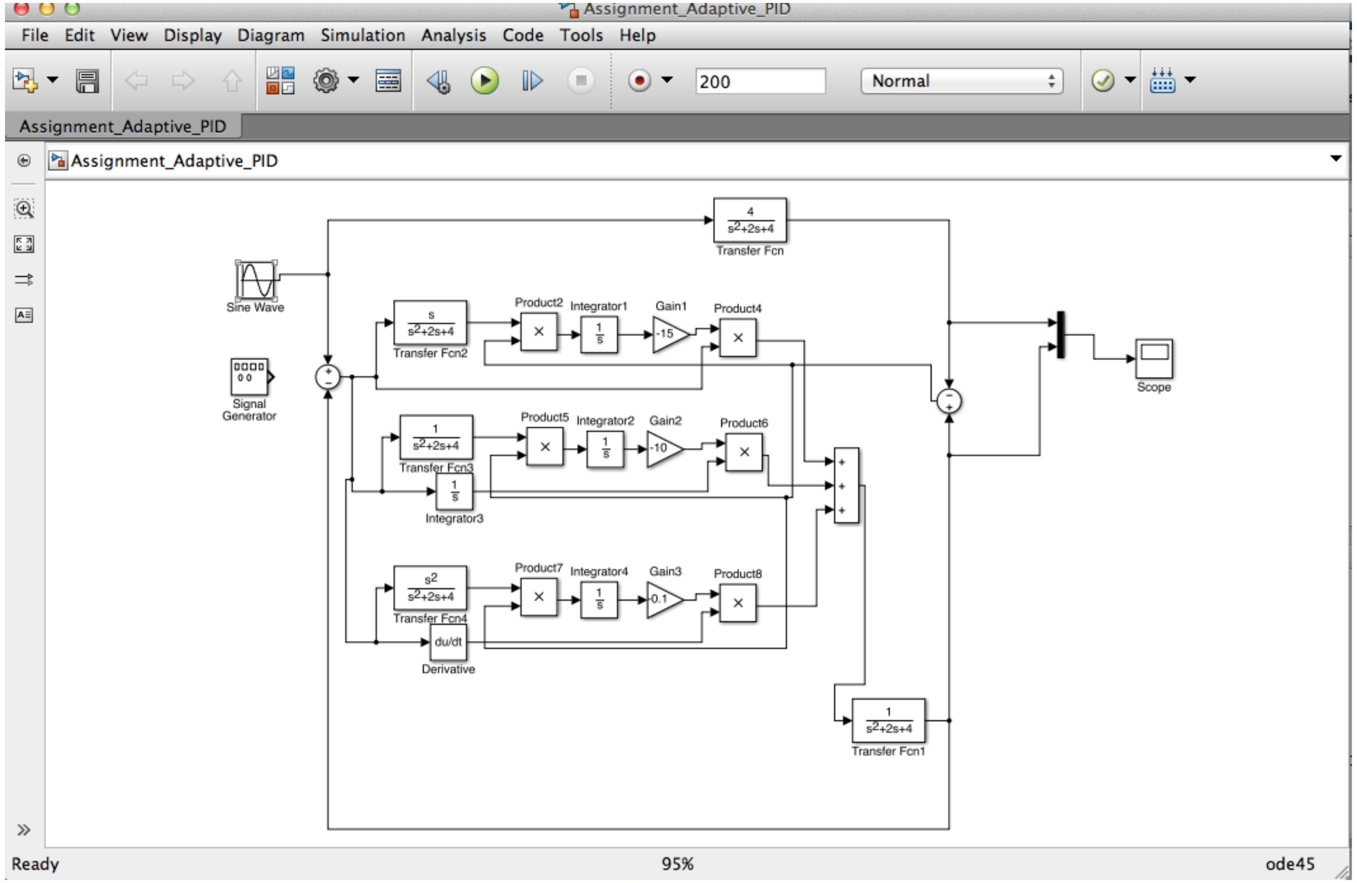
Control System Toolbox

- Contains a set of functions relation to control system design.
- Can be used together with other MATLAB functions or functions from other toolboxes.



Simulink

- More graphical.
- Code writing is minimal.



EXERCISES

Review questions

- Name 3 applications of feedback control system.
- Give 3 examples of open-loop systems.
- Give an example of what happen to a system that is unstable.
- Name 3 approaches to the mathematical modeling of control systems.
- How do we classify control systems?
- What are the steps involved in designing a control system?

Answers

- Name 3 applications of feedback control system.
  - Guided missiles, automatic gain control in radio receivers, satellite tracking antenna
- Give 3 examples of open-loop systems
  - Motor, low pass filter, inertia supported between two bearings
- Give an example of what happen to a system that is unstable
  - It follows a growing transient response until the steady-state response is no longer visible. The system will either destroy itself, reach an equilibrium state because of saturation in driving amplifiers, or hit limit stops.
- Name 3 approaches to the mathematical modeling of control systems.
  - Transfer function, state-space, differential equations
- How do we classify control systems?
  - Open-loop control system and closed-loop control system
  - Linear and non-linear control systems
  - Time-invariant and time-varying control systems
  - Continuous and discrete control systems
  - Single input-single output (SISO) and multi input-multi output (MIMO)
  - Lumped parameter and distributed parameter control systems

Answers

- What are the steps involved in designing a control system?

STEP 1
- Transform requirements into physical systems

STEP 2
- Draw a functional block diagram

STEP 3
- Create a schematic

STEP 4
- Develop mathematical model (block diagram)

STEP 5
- Reduce block diagram

STEP 6
- Analyze & Design

Problem 1

A variable resistor, called a potentiometer is given below. The resistor is varied by moving a wiper arm along a fixed resistance. The resistance from A to C is fixed, but the resistance from B to C varies with the position of the wiper arm. If it takes 10 turns to move the wiper arm from A to C, draw a block diagram of the potentiometer showing the input variable, output variable and (inside a block) the gain etc.

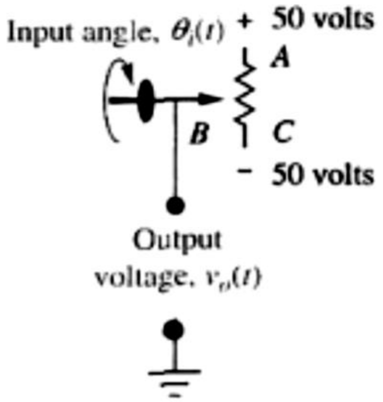


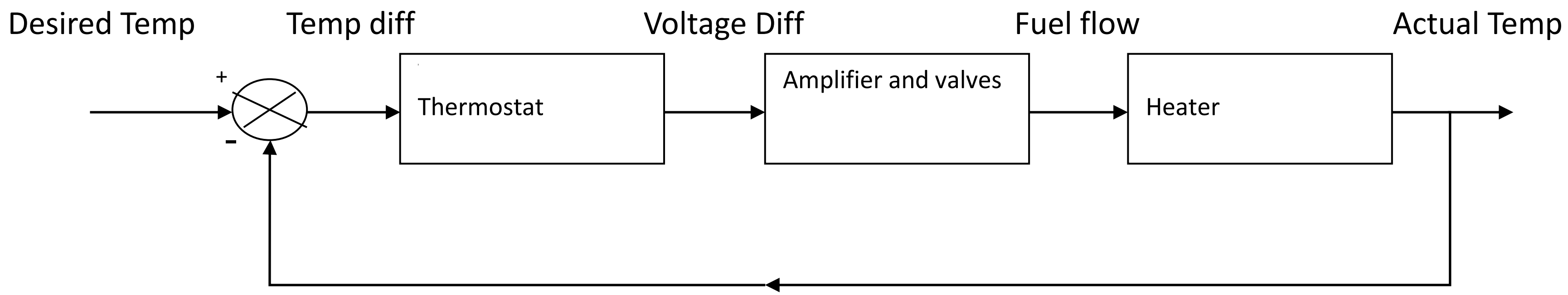
FIGURE P1.1 Potentiometer

Solution 1

Problem 2

A temperature control system operates by sensing the difference between the thermostat setting and the actual temperature and then opening a fuel valve an amount proportional to this difference. Draw a functional closed-loop block diagram, identifying the input and output transducers, the controller and the plant. Further, identify the input and output signals of all subsystems previously described.

Solution 2


Desired Temp
Temp diff
Voltage Diff
Fuel flow
Actual Temp
+
-
Thermostat
Amplifier and valves
Heater

END OF CHAPTER 1