ECOR1044: Introduction

Background Information

Course Structure

- **Lectures:**
  - Will cover various material relating to theory, applications, lab contents, and general engineering practice
- **Labs:**
  - Lab Reports
  - Track/record your progress
    - Results
    - Pictures of setups
    - Any issues/challenges
  - Checkout marks
- **Group Project**

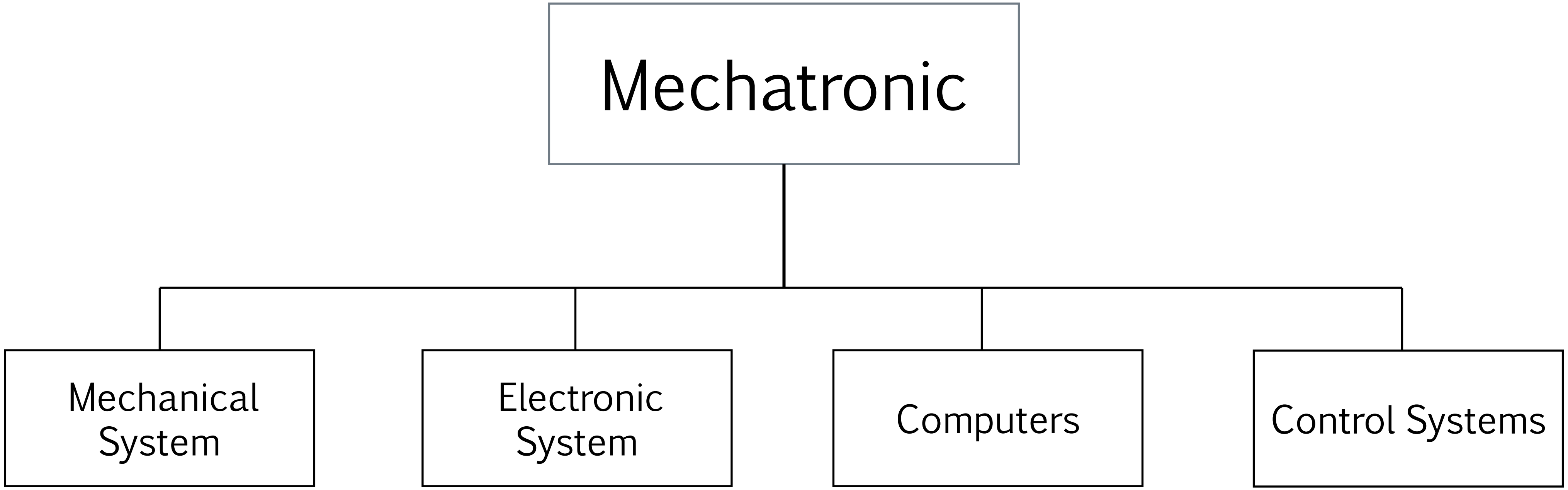
What is Mechatronics?

- Multidisciplinary engineering integrating **mechanical systems, electrical engineering, control systems, and computer systems.**

- Mechatronics as a modern solution for complex problems across industries like manufacturing, healthcare, and robotics.

https://www.rolandberger.com/en/Insights/Publications/Humanoid-robots-From-science-fiction-to-reality.html

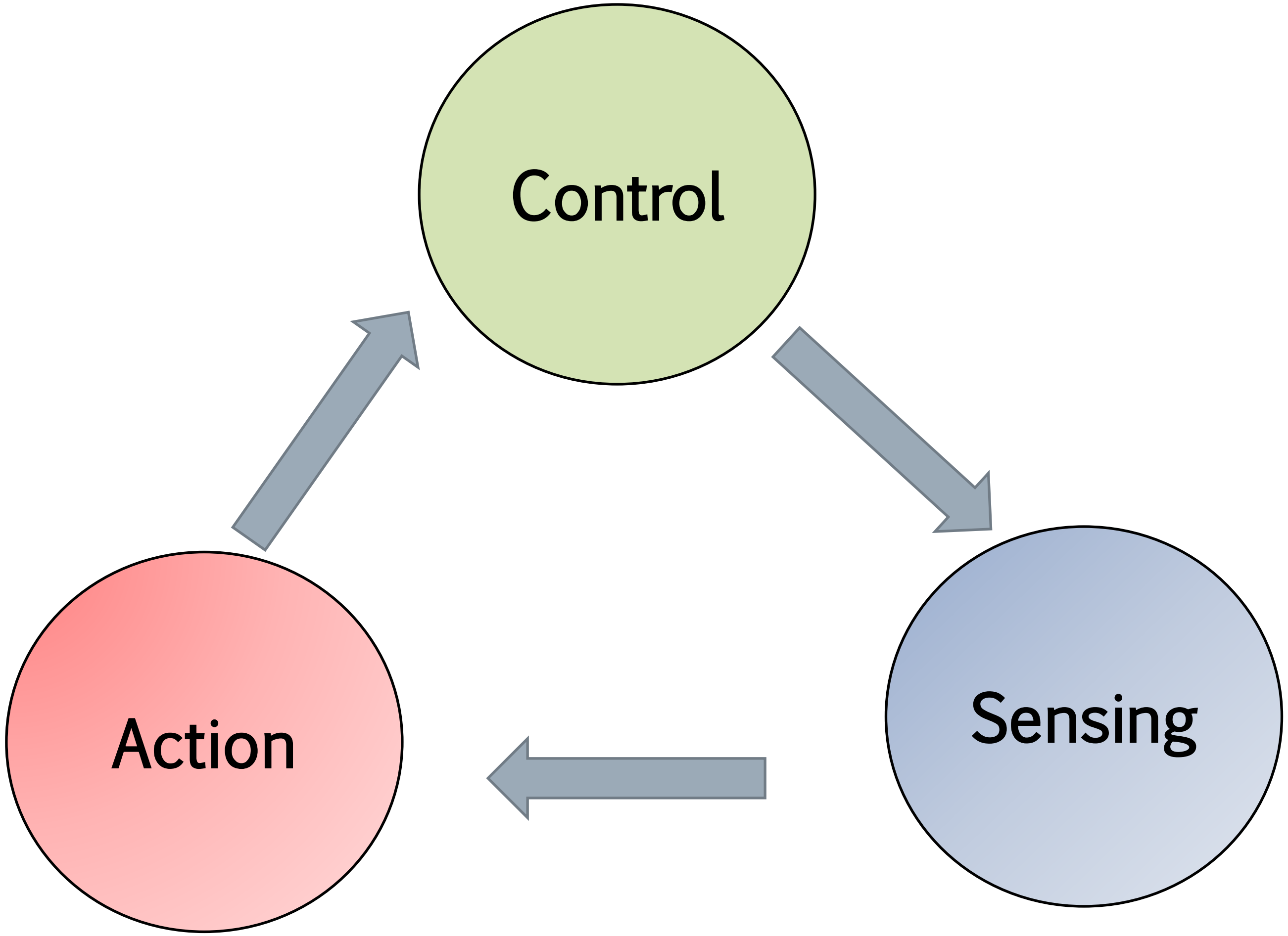
What is Mechatronics?



What is Mechatronics?

- **Mechanical System**
  - Solid mechanics
  - Dynamics and vibrations
  - Kinematics
- **Electronics**
  - Sensors
  - Power systems (batteries, converters, etc.)
  - Communication systems
- **Control System**
  - Classical control
  - Modern control
  - Optimal control
- **Computer**
  - Design computation
  - Microprocessor integration
  - Microcontroller

Model of Mechatronic System



Model of Mechatronic System

- **Sensing System**
  - Sensors
  - Analog to Digital and Digital to Analog conversion

- **Control**
  - Open Loop
  - Closed loop

- **Action**
  - Motors
  - Actuators

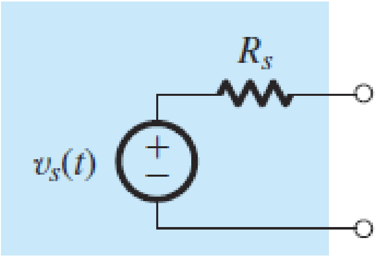
Sensors

Role of Sensors:

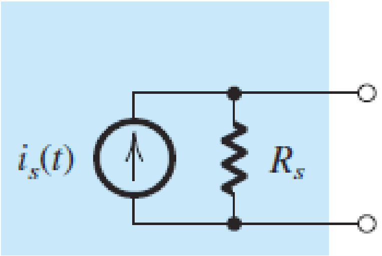
- Detecting physical parameters (temperature, light, pressure).
- Examples: Proximity sensors, accelerometers.
- Function: Provide data to the control system for real-time decision-making.

https://builtin.com/articles/iot-sensors

Sensors

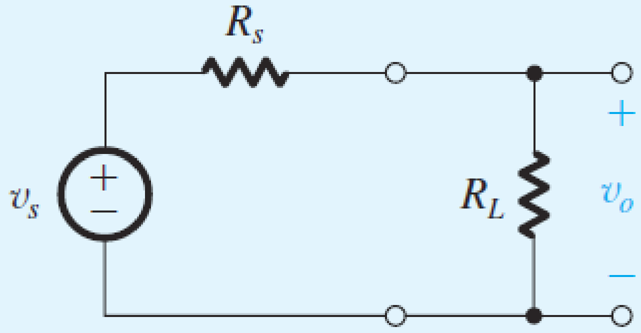


Thévenin form

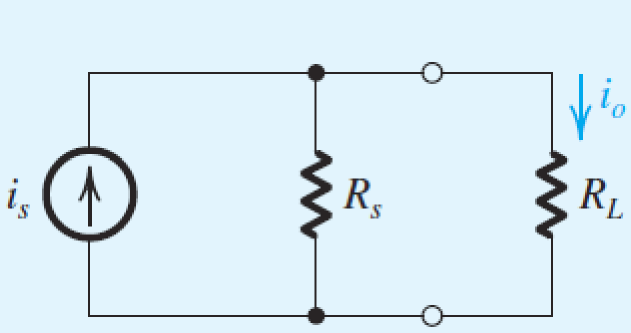


Norton form

- **Sensors** use electrical signal, like **voltage or current**, to describe **signals** from physical world. Examples: temperature, pressure, speed, etc.



(a)



(b)

$$v_o = v_s \frac{R_L}{R_L + R_s}$$

$$v_o \simeq v_s$$

$$R_s \ll R_L$$

ideally $R_s = 0$

$$i_o = i_s \frac{R_s}{R_s + R_L}$$

$$i_o \simeq i_s$$

$$R_s \gg R_L$$

ideally $R_s = \infty$

Control Systems

- Control engineering deals with the design (and implementation) of control systems using **linear**, **time-invariant** mathematical models representing actual physical **nonlinear**, **time-varying** systems with parameter **uncertainties** in the presence of external **disturbances**.

- A challenge for control engineers today is to be able to create **simple**, yet **reliable** and **accurate** mathematical models of many of our modern, complex, interrelated, and interconnected systems.

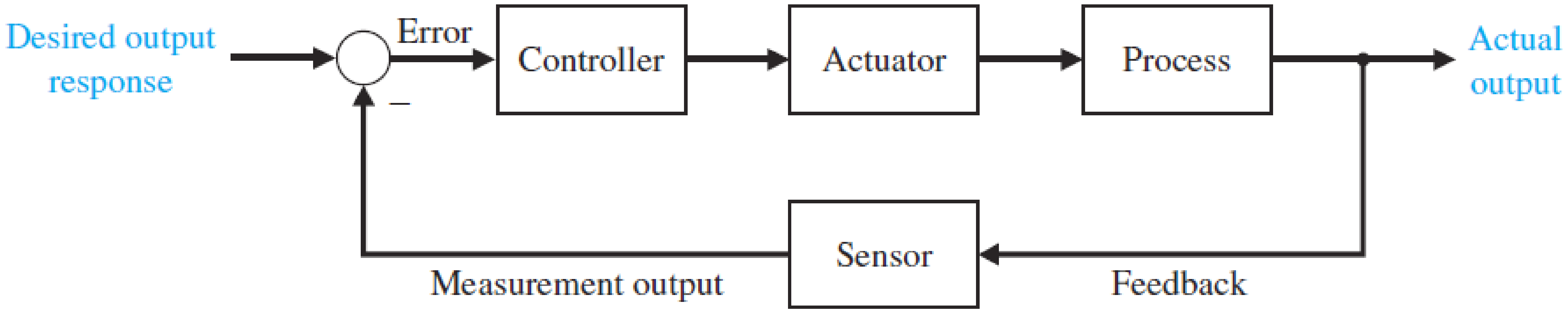
- Control Systems can be classified as **SISO** control systems and **MIMO** control systems based on the number of inputs and outputs present.

- Open- and closed-loop feedback control systems will be discussed.

- Illustrative examples of control systems will be shown/discussed.

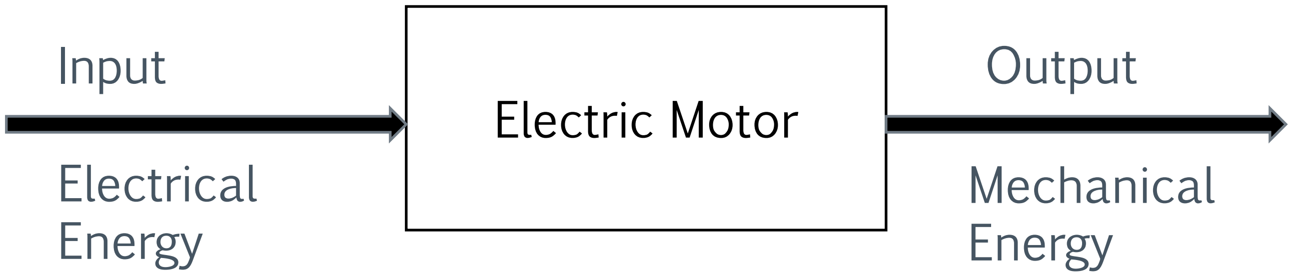
Control Systems

- A control system is an interconnection of components forming a system configuration that will provide a **desired system response**.
- A **sensor** is a device that provides a measurement of an external signal.
- An **actuator** is a device employed by the control system to alter or adjust the environment.
- The extremely important step of the overall design and implementation process is designing the control systems, such as PID controllers, etc.



Open-Loop Control Systems

Open Loop



Advantages:

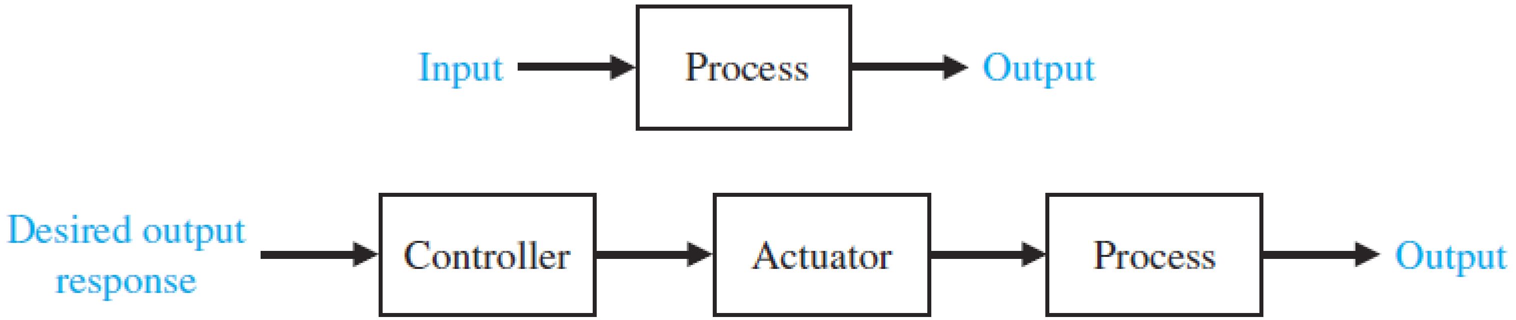
- Simplicity
- Low Cost
- Less maintenance
- Quick Response

Disadvantages:

- Inaccuracy
- Lack of Flexibility
- Sensitive to disturbances

Open-Loop Control Systems

- Open-loop control system

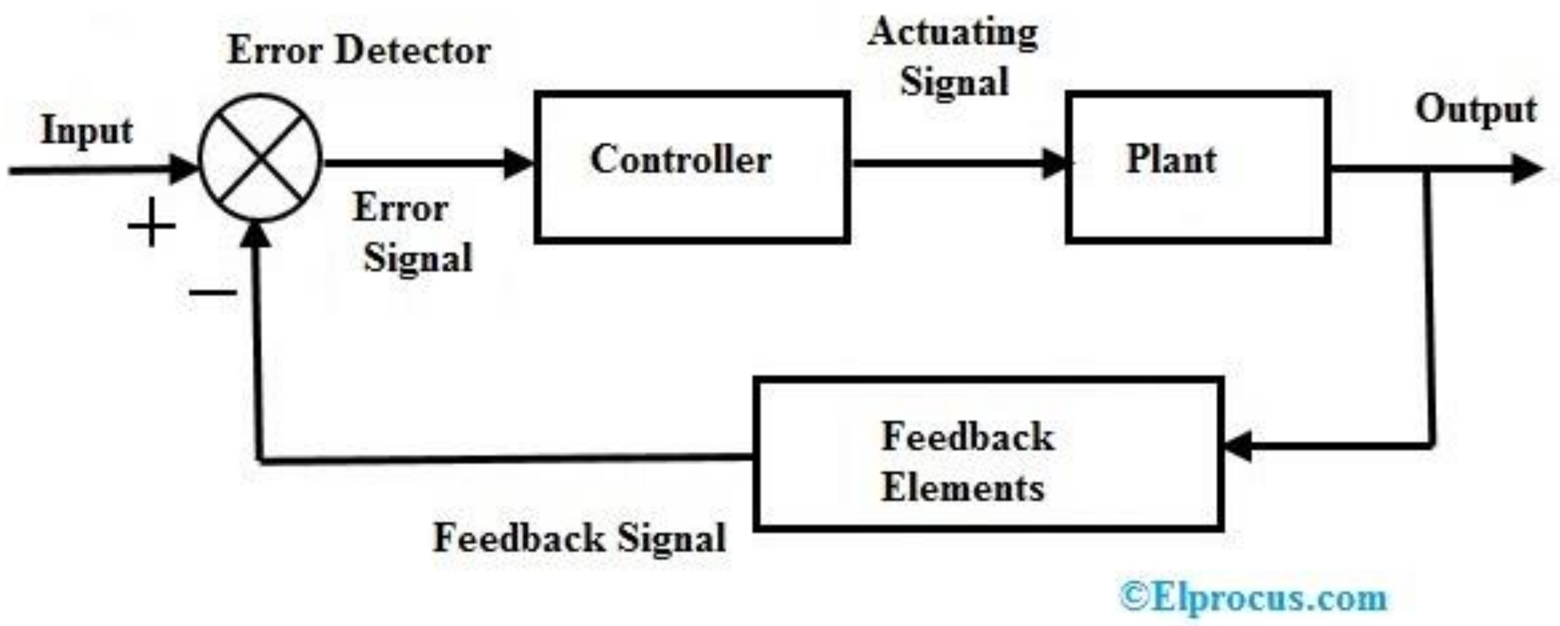


An open-loop control system utilizes an actuating device to control the process directly without using feedback.

- Example: a microwave oven set to operate for a **fixed** time.
- An open-loop control system uses a controller and an actuator to obtain the desired response.

Closed-Loop Control Systems

Closed Loop



Closed-Loop Control Systems

Advantages:

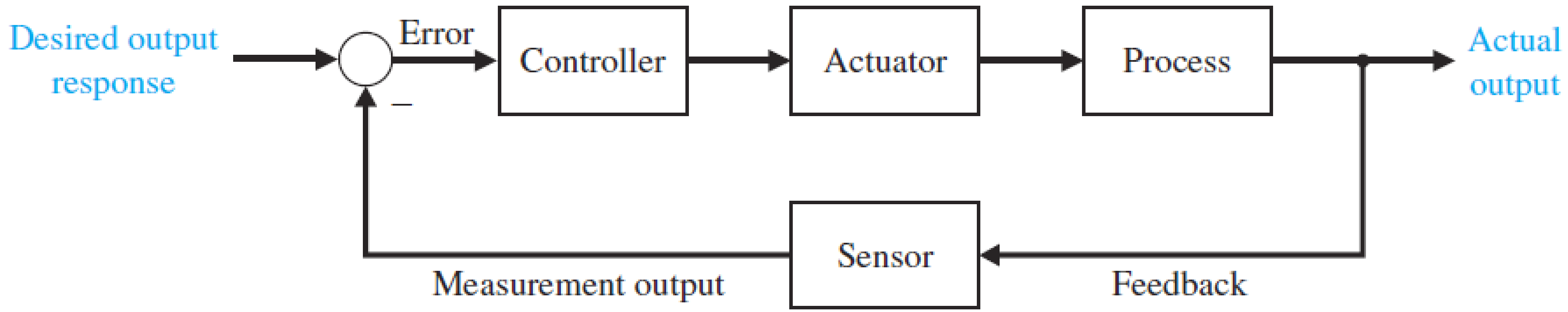
- Accuracy
- Adaptability
- Stability in Dynamic Conditions
- Improved Performance

Disadvantages:

- Complexity
- Higher Cost
- Slower Response
- Maintenance

Closed-Loop Control Systems

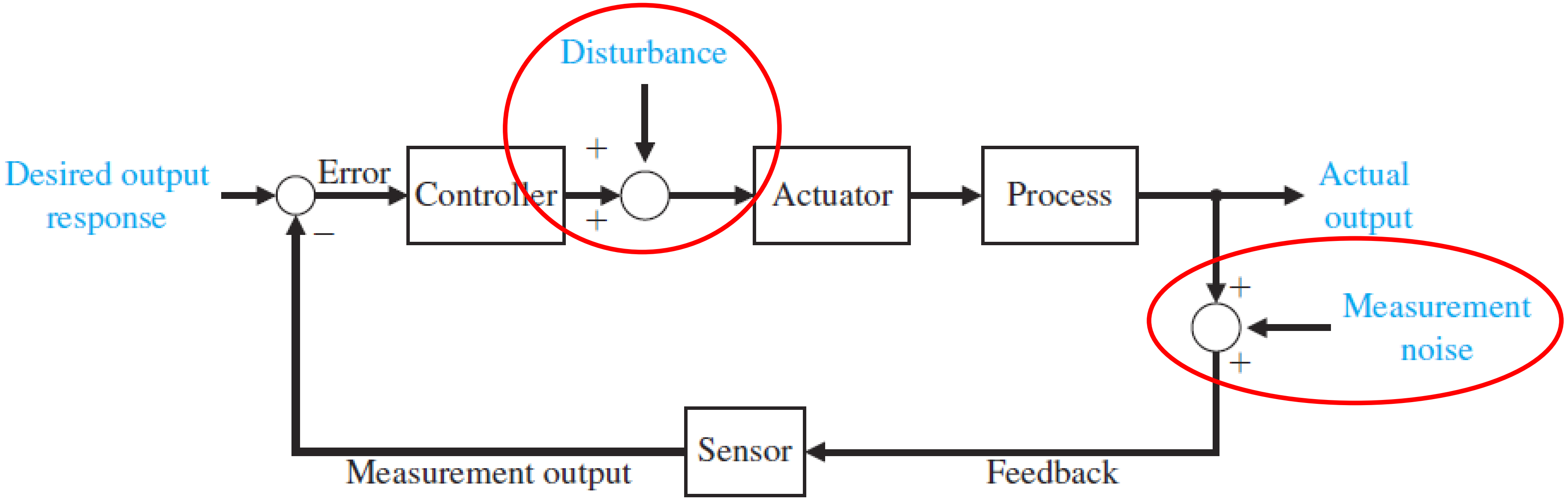
- Closed-loop control system:



A closed-loop control system uses a measurement of the output and feedback of this signal to compare it with the desired output (reference or command).

- Advantages: ability to **reject external disturbances** and improve measurement **noise attenuation**.
- An example of a closed-loop control system is a person **steering** an automobile by **looking** at the auto's **location** on the road and **making** the appropriate **adjustments**.

Disturbance Rejection



A closed-loop control system uses a measurement of the output and feedback of this signal to compare it with the desired output (reference or command).

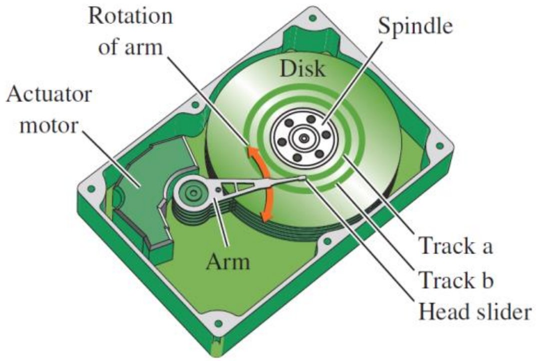
- We incorporate the **disturbances** and measurement noise in the block diagram as **external inputs**.

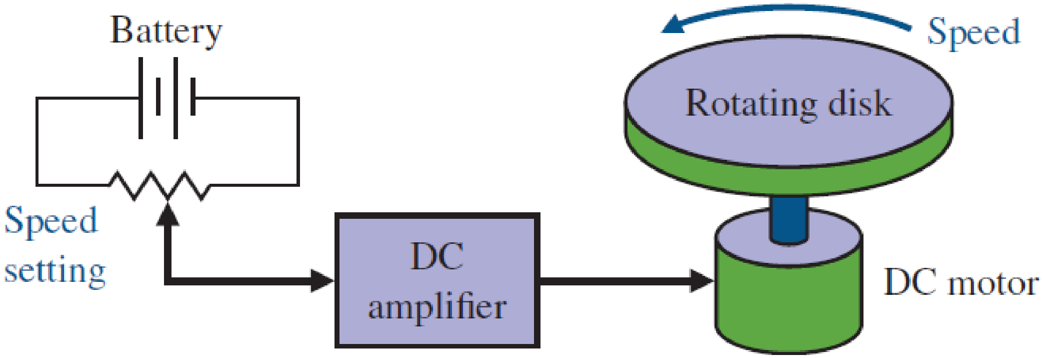
Open-Loop vs. Closed-Loop

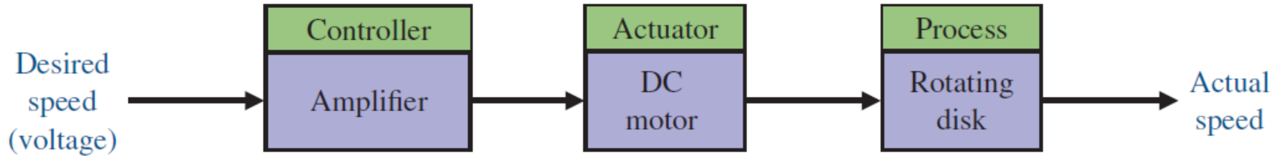
Open Loop Control Systems	Closed Loop Control Systems
Control action is independent of the desired output.	Control action is dependent of the desired output.
Feedback path is not present.	Feedback path is present.
These are also called as **non-feedback control systems**.	These are also called as **feedback control systems**.
Easy to design.	Difficult to design.
These are economical.	These are costlier.
Inaccurate.	Accurate.

Design Example: Rotating Disk Speed Control

- Many modern devices employ a rotating disk held at a **constant speed**; e.g.: hard disk drive.
- Our goal is to design a system for rotating disk speed control that will ensure that the **actual speed** of rotation is **within a specified percentage of the desired speed**.
- a **DC motor** is the **actuator** because it provides a speed proportional to the applied motor voltage.
- Open loop design:

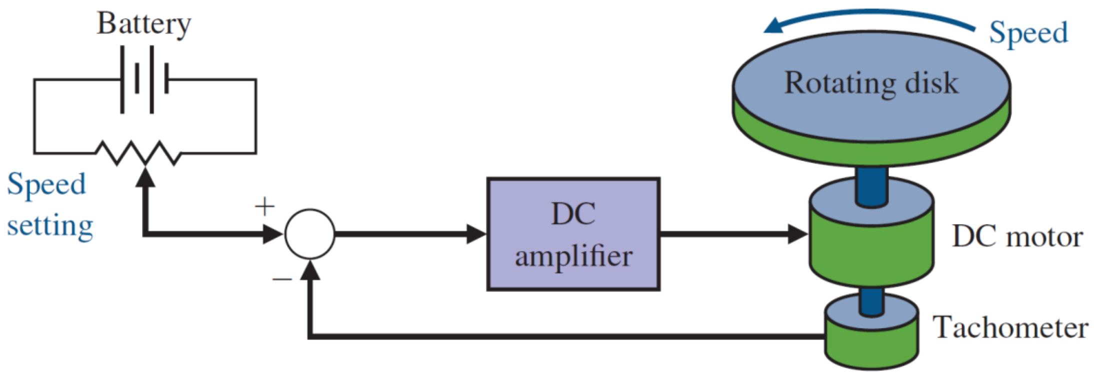


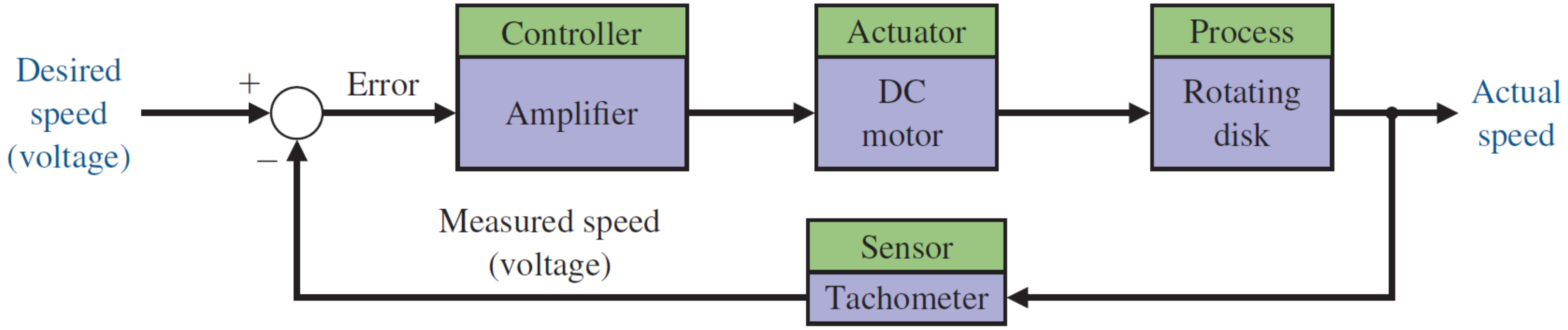




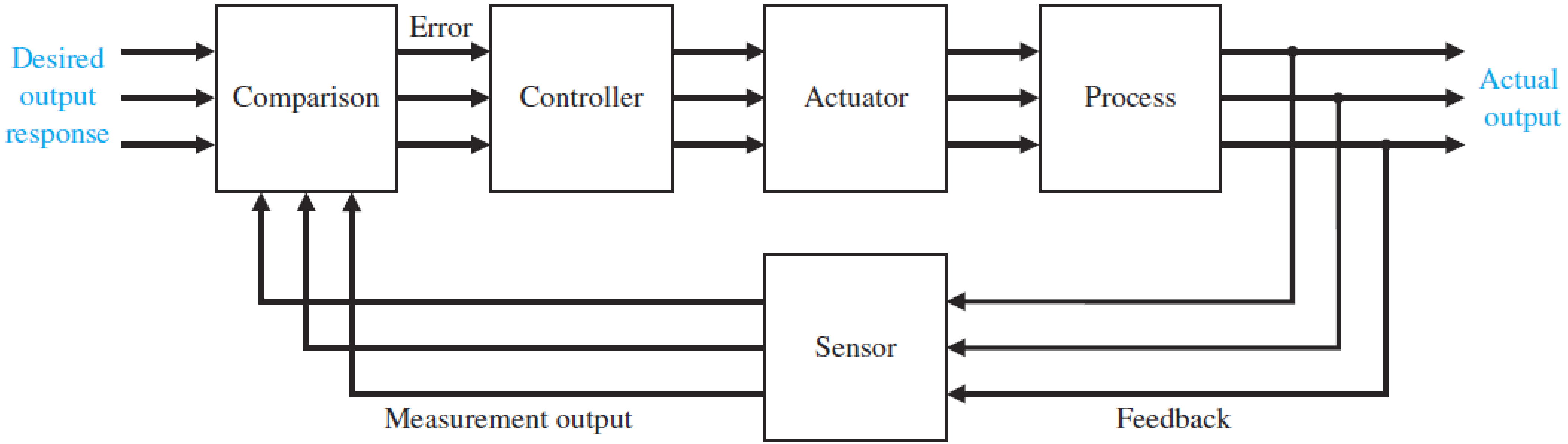
Design Example: Rotating Disk Speed Control

- Closed-loop design:
- To obtain a feedback system, we need to select a sensor.





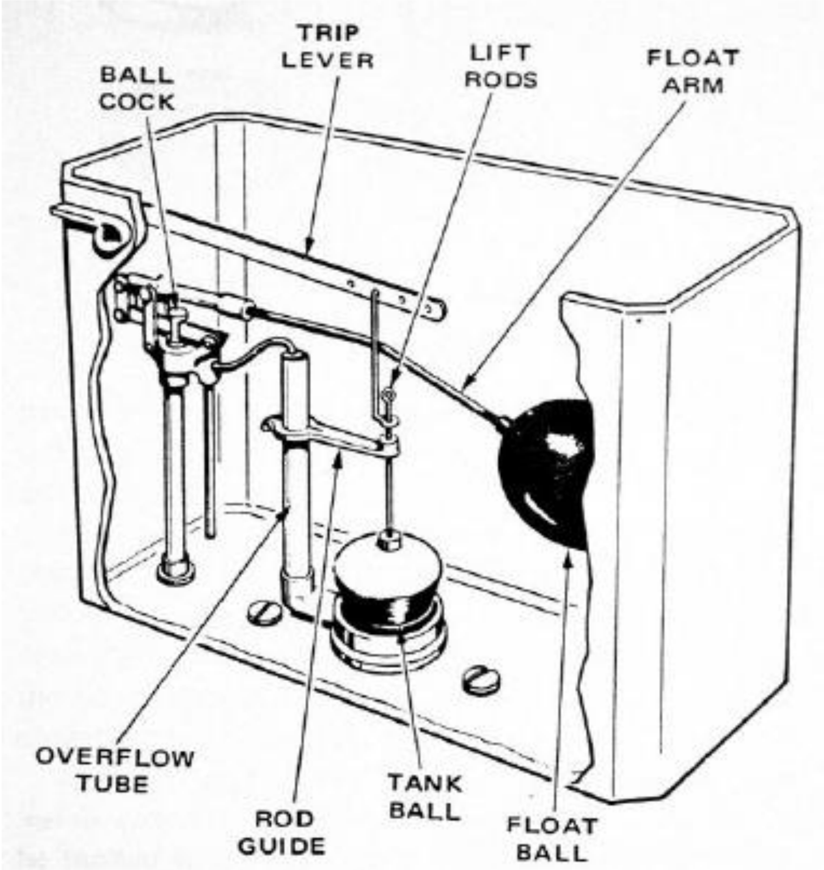
Multivariable Control Systems



› Example: helicopters, quadrotors, etc.

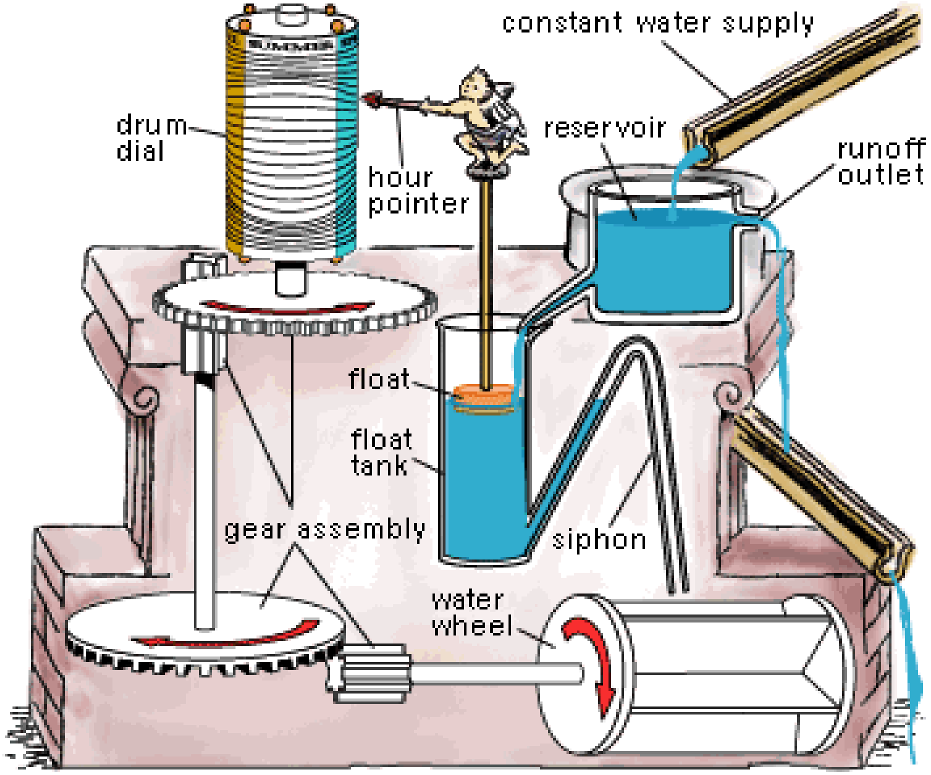
Introduction: Application

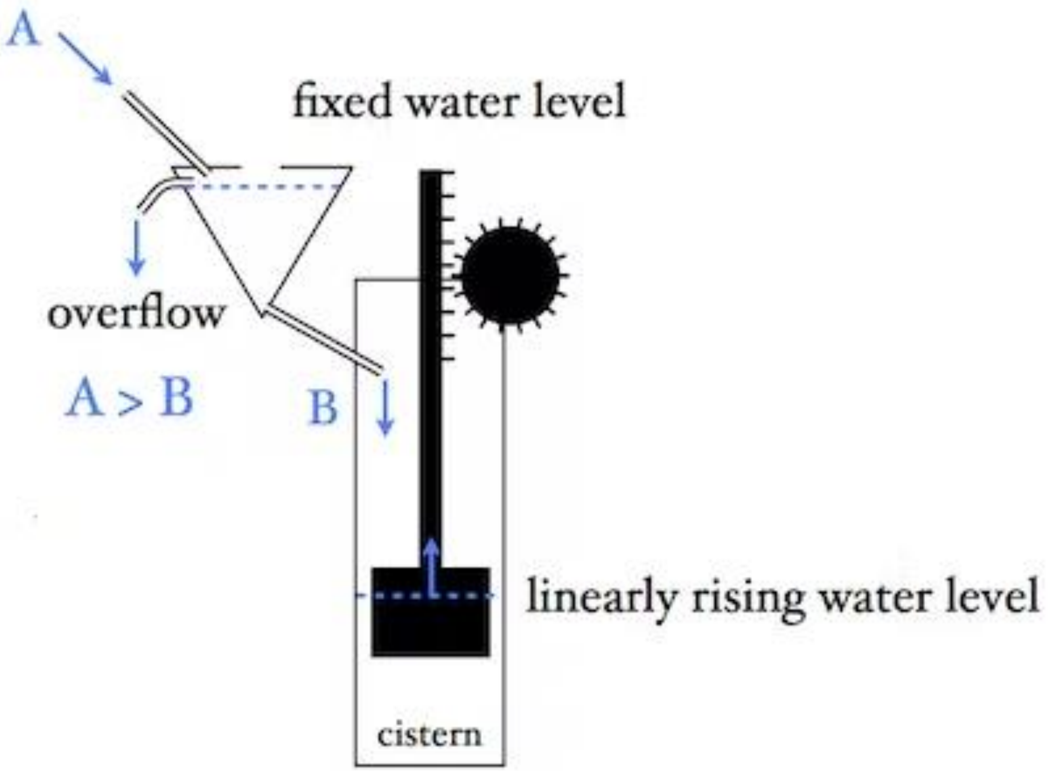
- The toilet employs a control mechanism that ensures that the tank is filled to a **set reference level**. Similar systems are used in other applications where fluid levels need to be regulated.



Introduction: History

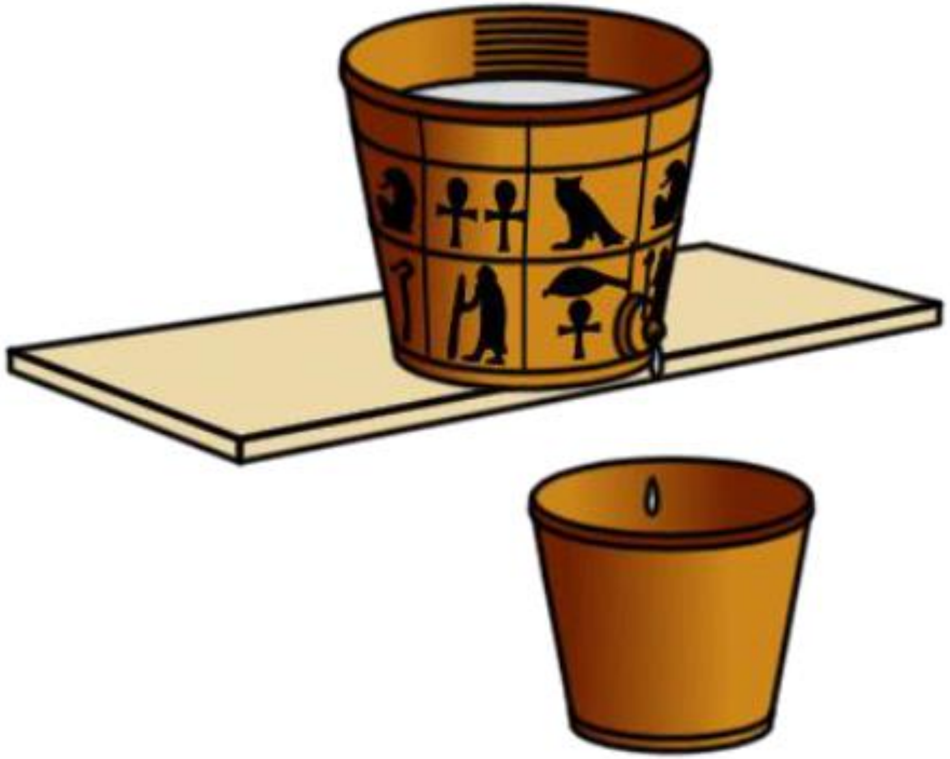
- The first applications of feedback control appeared in the development of float regulator mechanisms in Greece in the period 300 to 1 B.C.
- The water clock of Ktesibios used a float regulator.





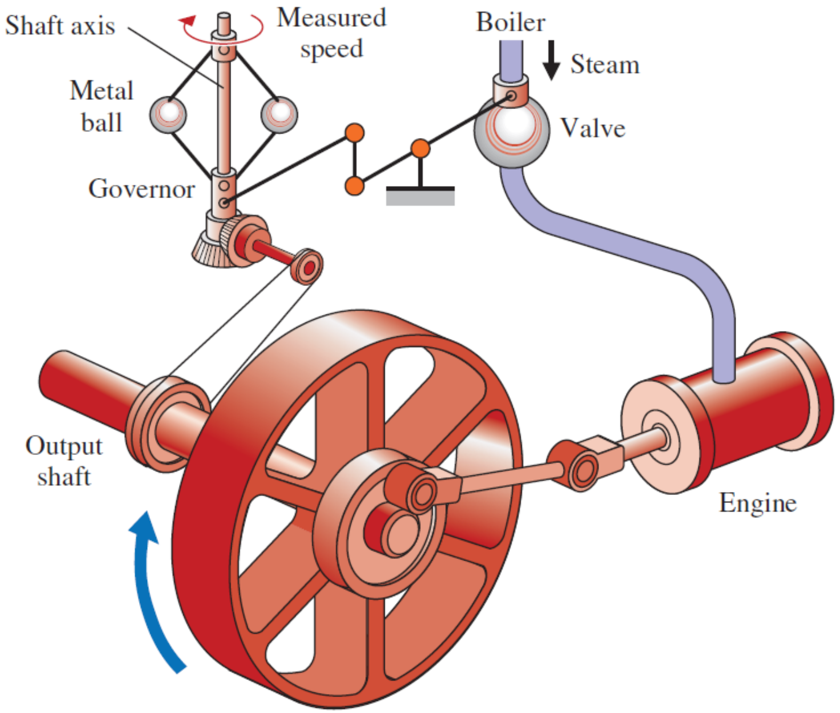
Ancient Egyptian Open-Loop Water Clock

- Ancient settlements grew around water sources.
- Egyptians made use of water to track time.



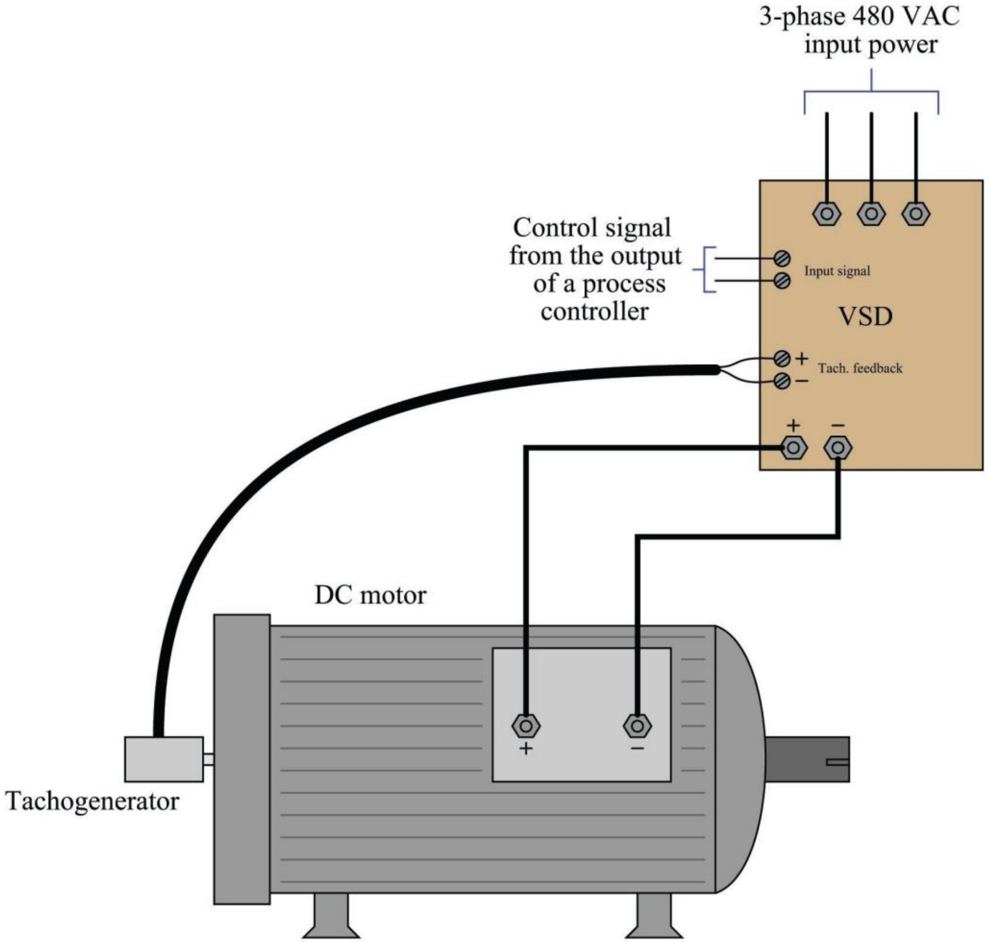
Introduction: History

- An oil lamp devised by Philon in approximately 250 B.C. used a float regulator in an oil lamp for maintaining a constant level of fuel oil.
- The first automatic feedback controller used in an industrial process is generally agreed to be James Watt's flyball governor, developed in 1769 for controlling the speed of a steam engine.



Control Systems

- Example of closed loop control



https://control.com/textbook/variable-speed-motor-controls/dc-motor-speed-control/

Action

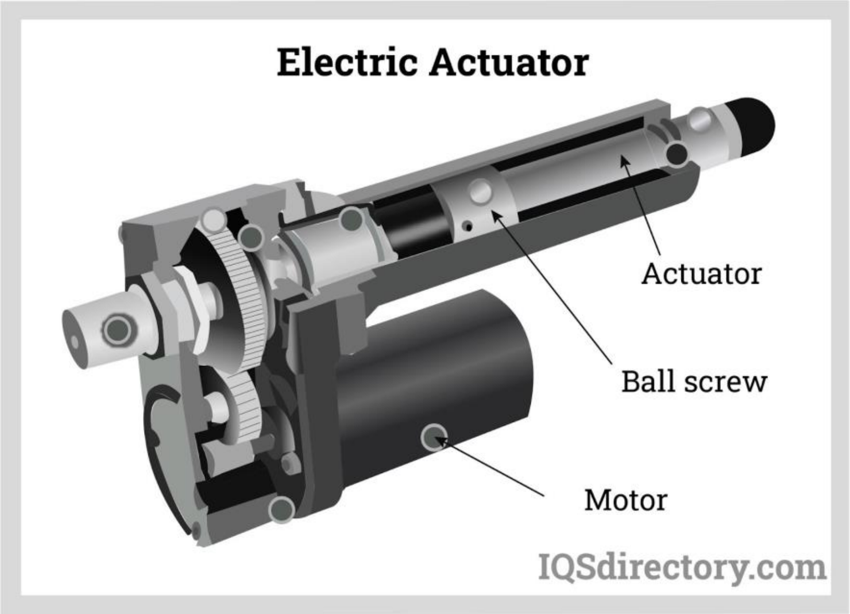
– Motors

https://en.wikipedia.org/wiki/AC_motor

Action

– Actuators

An actuator is a component of a device or machine that enables physical movement by transforming energy commonly electrical, pneumatic, or hydraulic into mechanical force.



Application of Mechatronics

Industrial Automation

Fully Automated car assembly lines using robotic arms.

https://www.wired.com/story/fords-smarter-robots-speeding-assembly-line/

Benefits: Increased efficiency, precision, and safety.

Application of Mechatronics

Robotics

Industrial robots, mobile robots

Example: Articulated robots in manufacturing

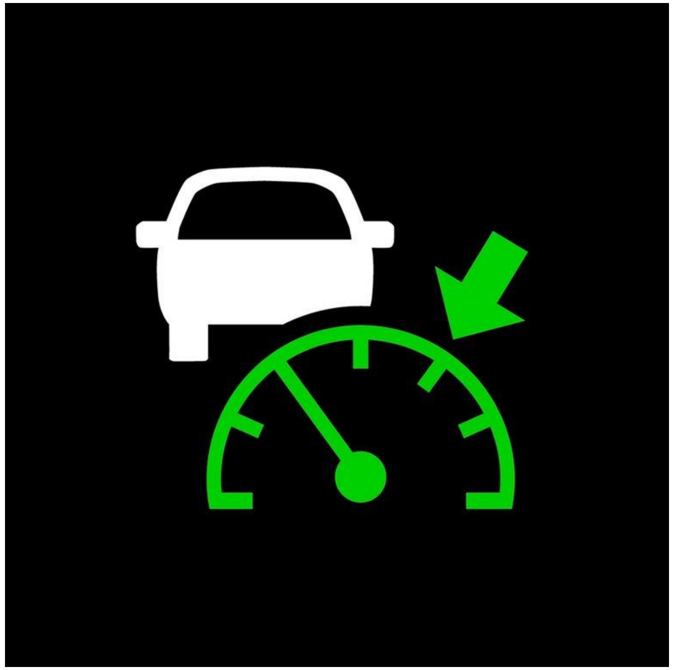
https://howtorobot.com/expert-insight/articulated-robots

Application of Mechatronics

Automotive application

Mechatronics in modern cars: Anti-lock Braking System (ABS), electronic stability, cruise control.

Future: Autonomous vehicles (self-driving cars).



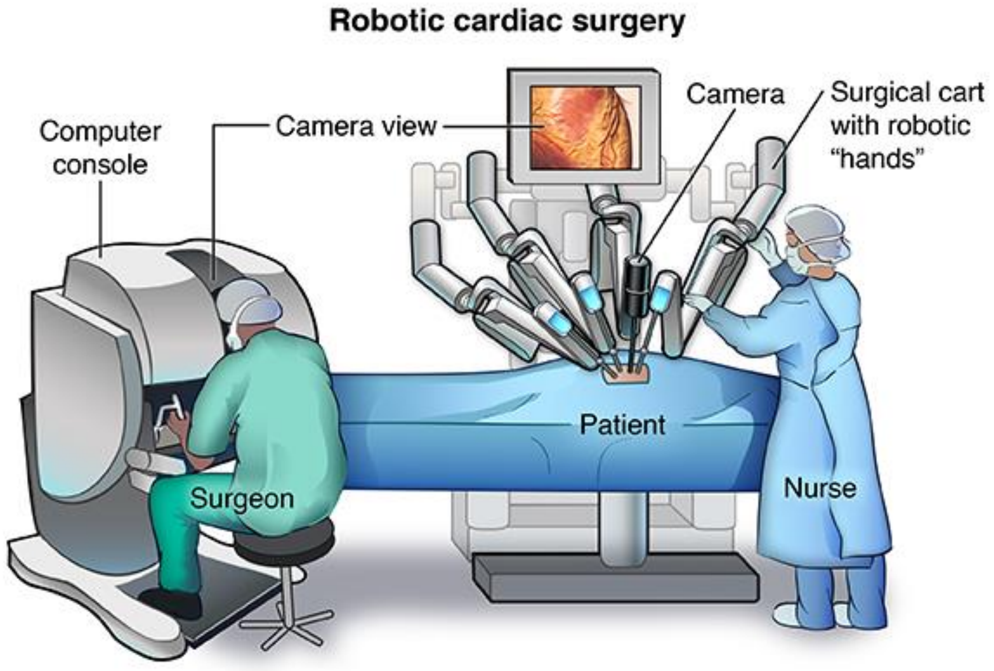
https://www.continental.com/en-us/products-innovation-1/safelythere/advanced-safety-technologies/adaptive-cruise-control/

Application of Mechatronics

Medical Devices

Examples: Da Vinci Surgical System, robotic-assisted surgery.

Importance: Precision and automation in medical care.



https://www.stanfordchildrens.org/en/topic/default?id=robotic-assisted-cardiac-surgery-135-11

Application of Mechatronics

Consumer Electronics

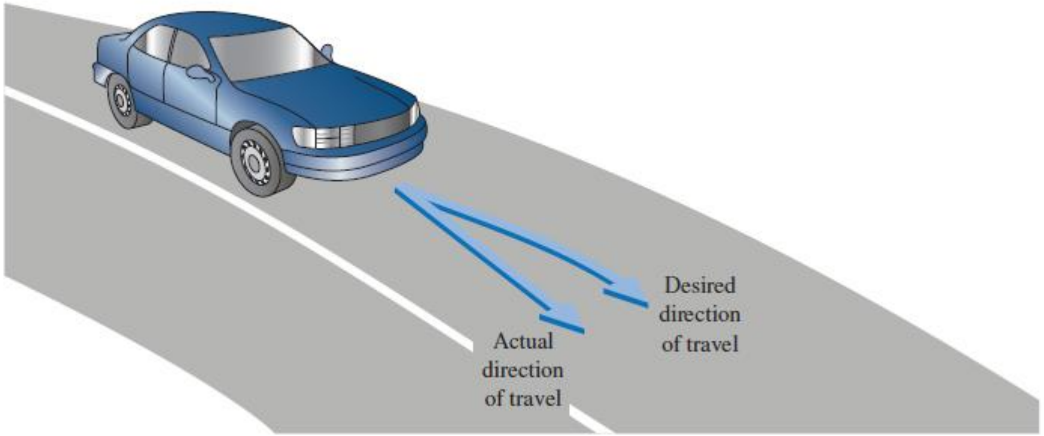
Mechatronics behind smart devices: Smart home systems, wearable technologies.

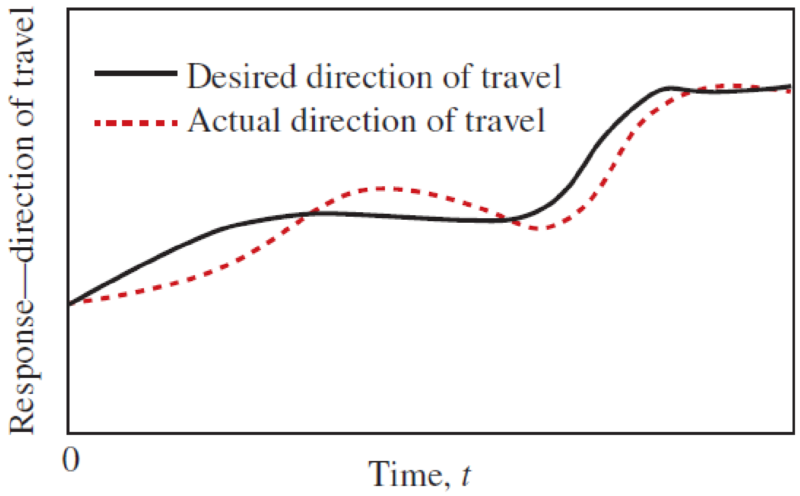
Examples: Smart thermostats, fitness trackers.

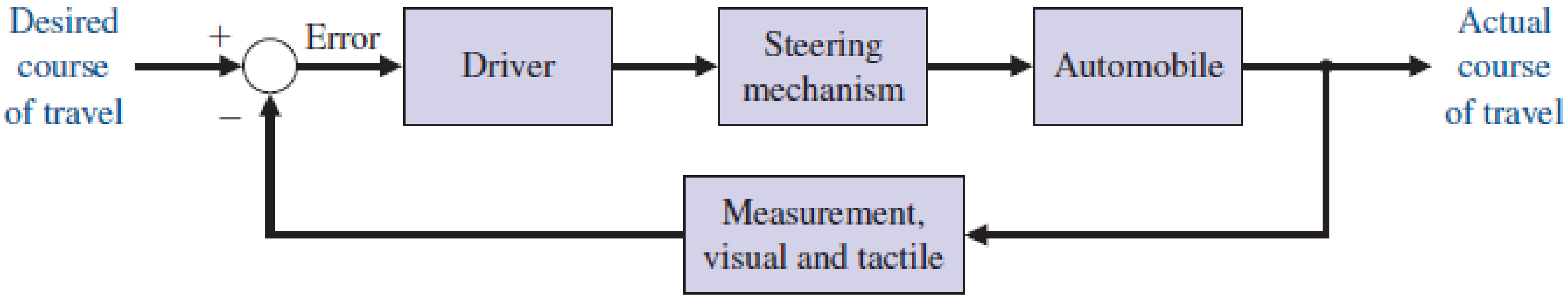
Benefits: Improved quality of life and efficiency.

https://www.indianic.com/blog/automation/what-is-smart-home-automation-system.html

Example: Automated Vehicles

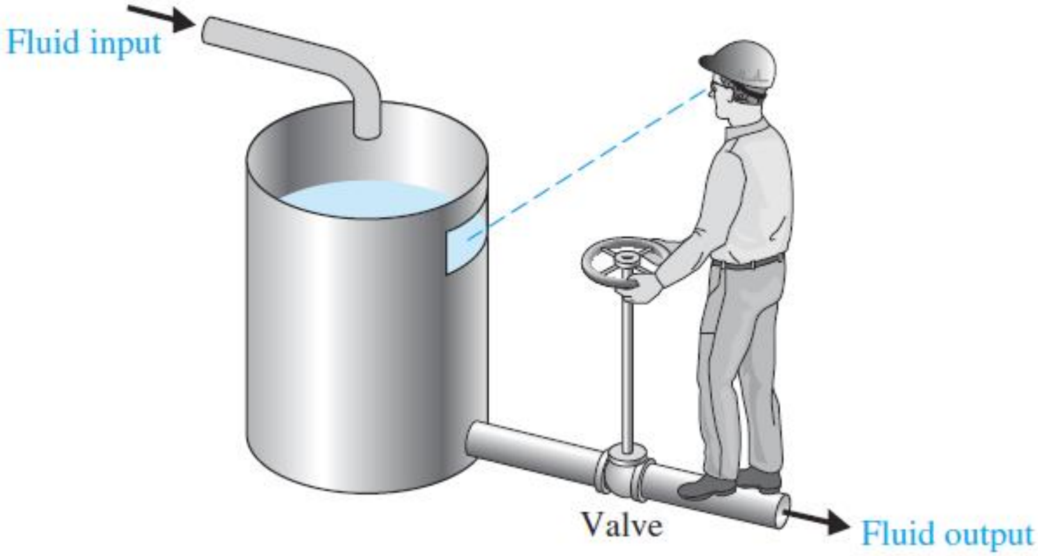




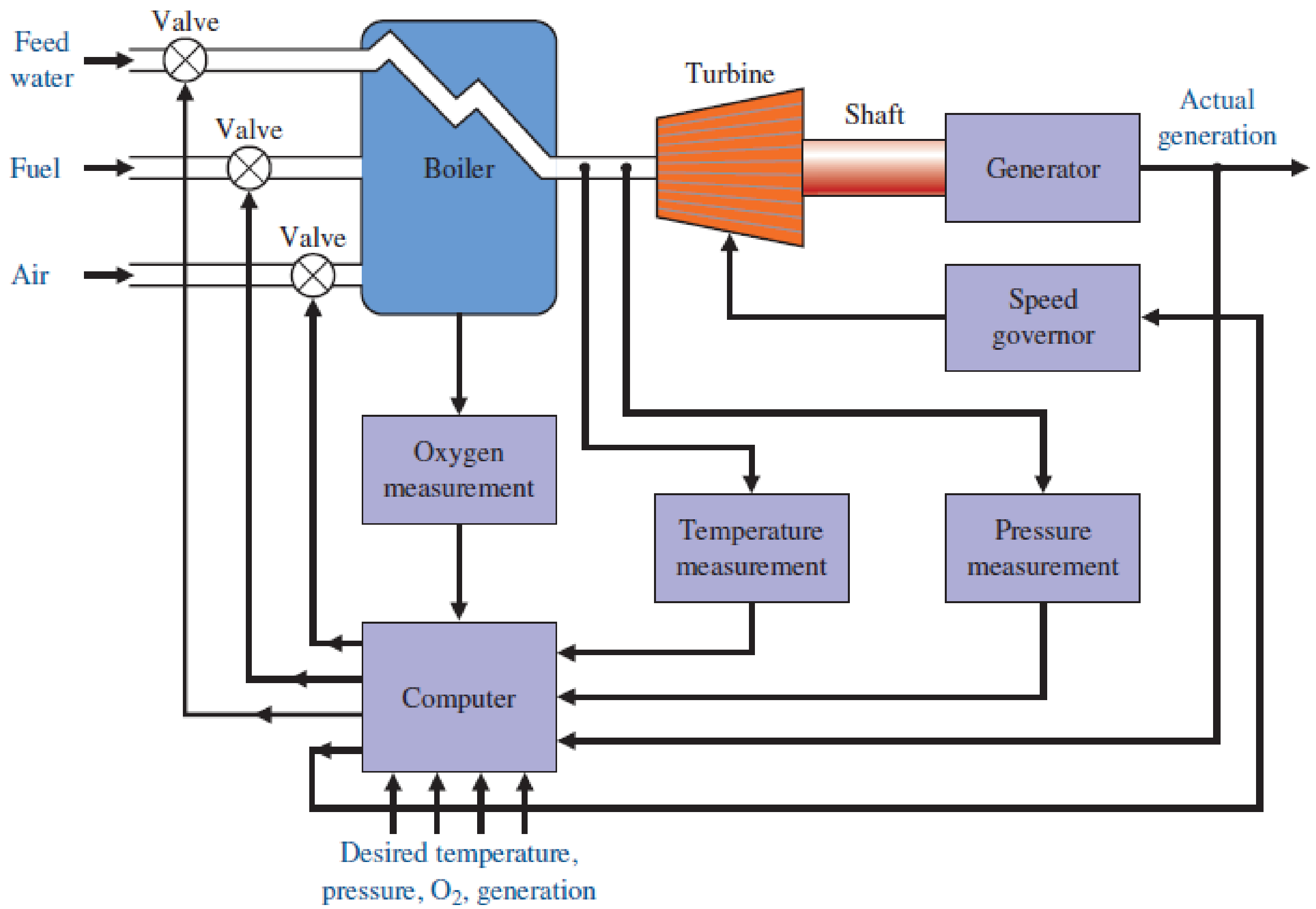


Example: Human-in-loop Control

- The input is a reference level of fluid that the operator is instructed to maintain. The power amplifier is the operator, and the sensor is visual.
- The operator compares the actual level with the desired level and opens or closes the valve (actuator), adjusting the fluid flow out, to maintain the desired level.



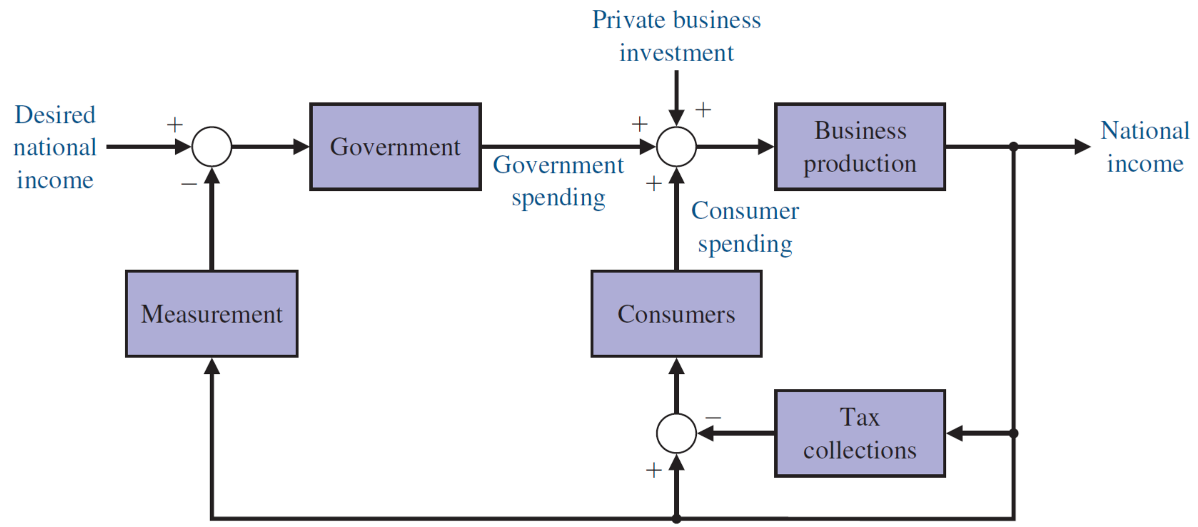
Example: Biomedical Engineering



- Most physiological control systems are closed-loop systems.

Example: Social, Economic, & Political Systems

- Society is composed of many feedback systems and regulatory bodies, which are controllers exerting the forces on society necessary to maintain a desired output.
- This type of model helps the analyst to understand the effects of government control and the dynamic effects of government spending.



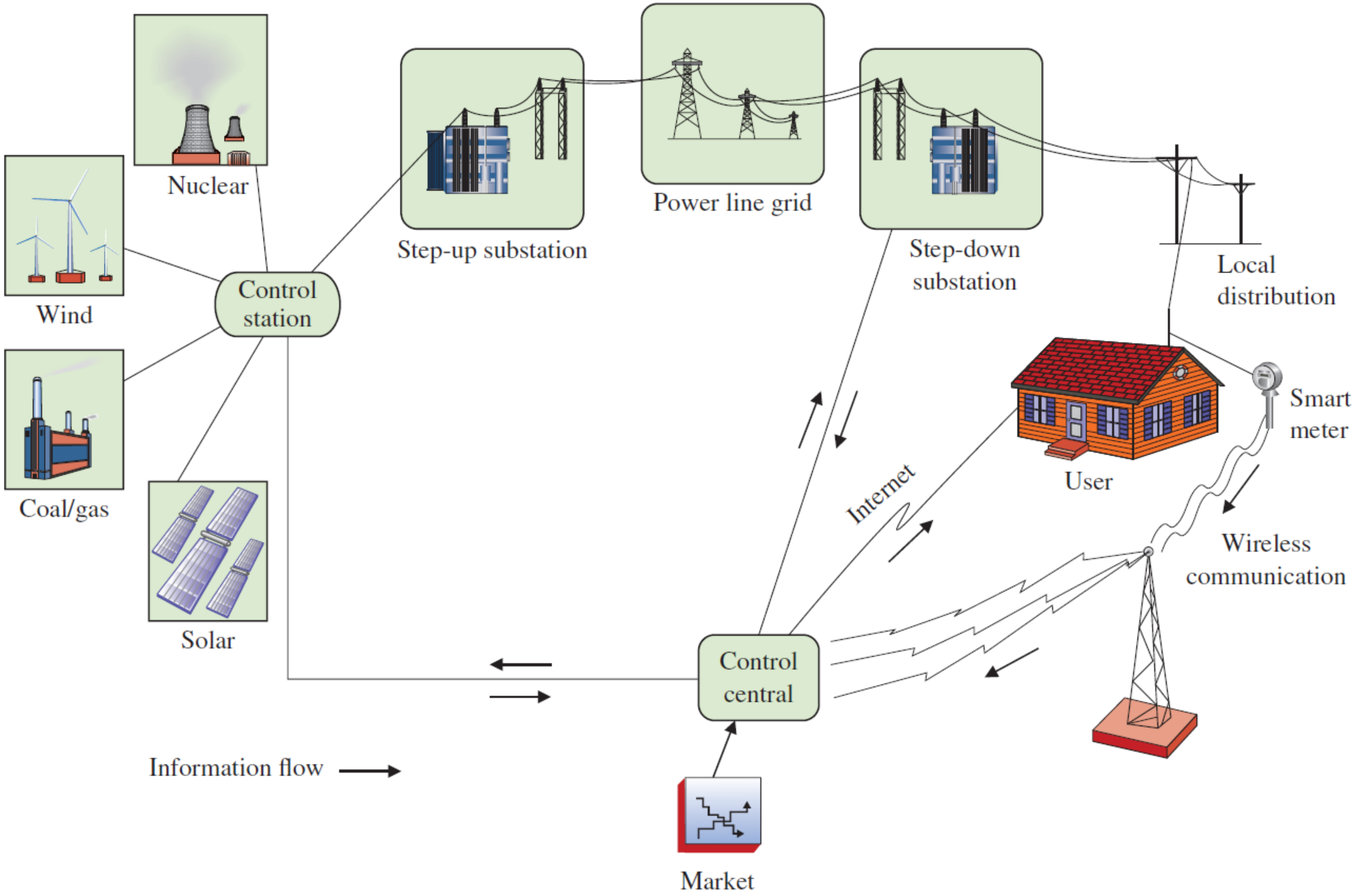
Example: Unmanned aerial vehicles

- Drones are unmanned but are usually controlled by ground operators.
- Naturally, they do not operate autonomously.
- Typical challenge is to develop control systems that will avoid in-air collisions.
- Ultimately, the goal is to employ the drone autonomously in such applications as aerial photography to assist in disaster mitigation, survey work to assist in construction projects.

Example: Wind Power

- Wind energy is one of the fastest-growing forms of energy generation in the United States and in other locations around the world.
- Advanced controls are required to achieve the level of efficiency required in the wind generation drive train.
- Maximum power point tracking (MPPT) is an electronic controller used with variable power sources to maximize energy extraction as conditions vary.

Design Example: Smart Grid Control System

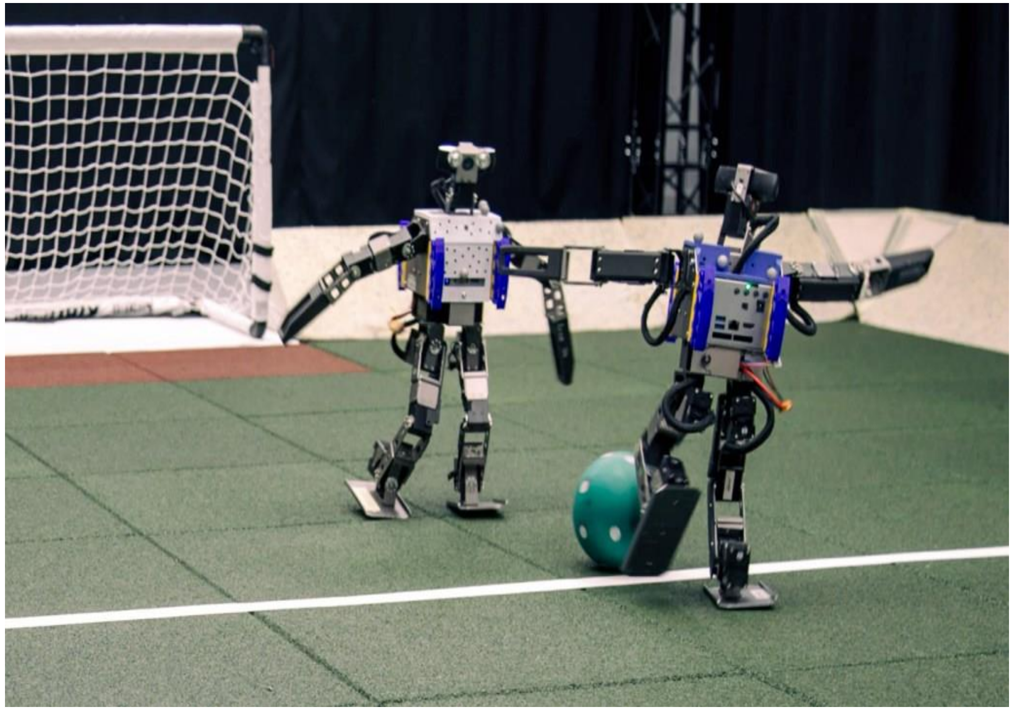


Artificial Intelligence in Mechatronics

Role of AI: Enhancing control systems, enabling autonomous decisions.

Example: AI-powered robots learning from real-time data.

Future: AI in smart factories, autonomous systems.



https://www.snexplores.org/article/ai-nimble-robots-reinforcement-learning

Questions?