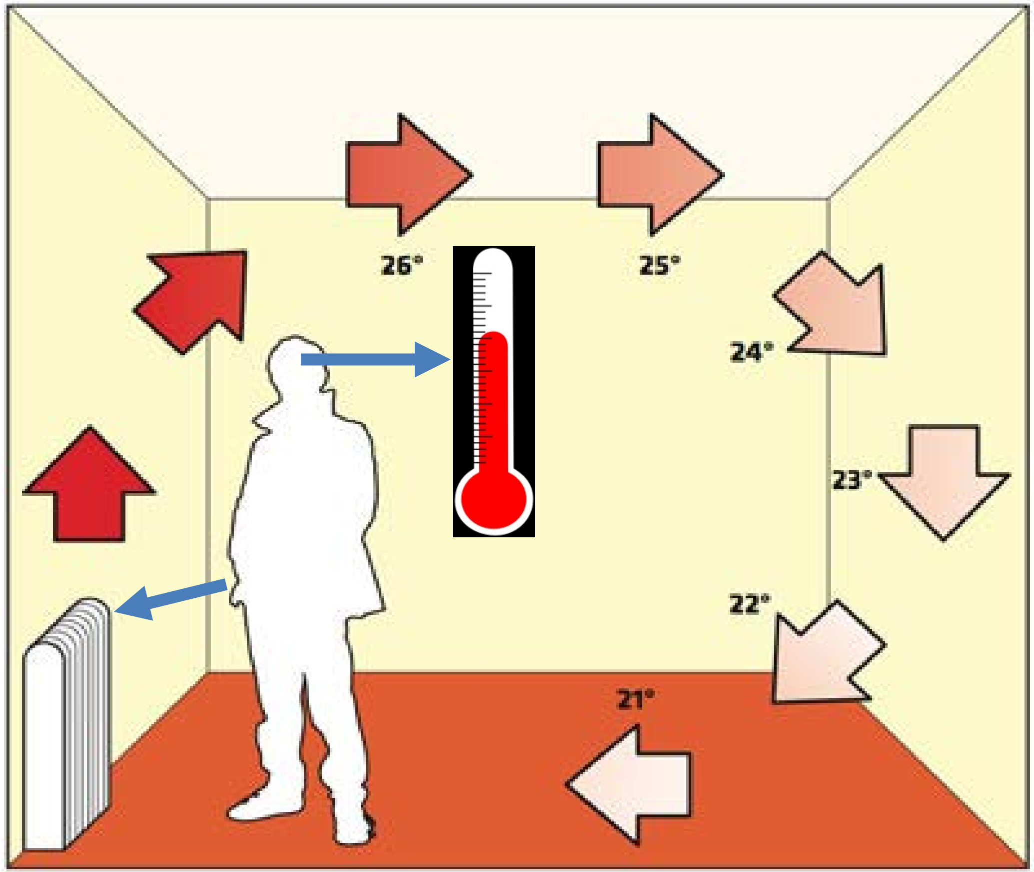
Automatic Control

Hak-Tae Lee

Introduction

What is Automatic Control?

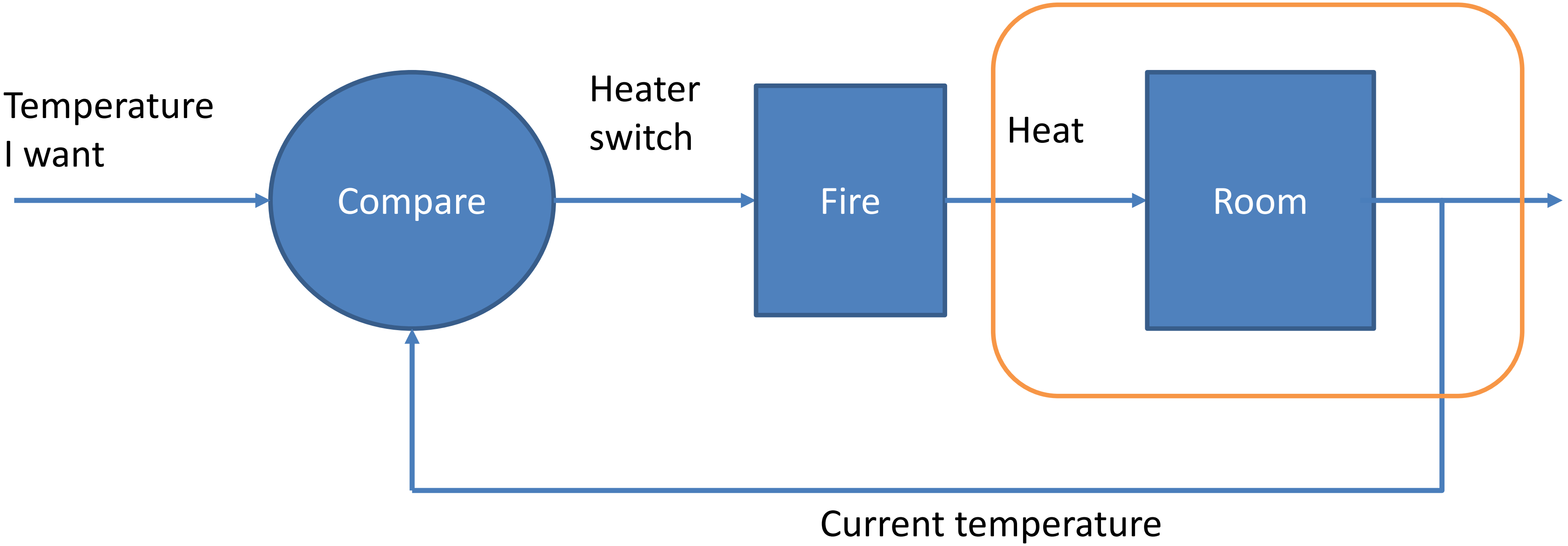


- Room heating example

What is Automatic Control?

- Set the temperature you want
- Check the thermometer
  - If the temperature is higher, turn off the heater
  - If the temperature is lower, turn on the heater

Diagram

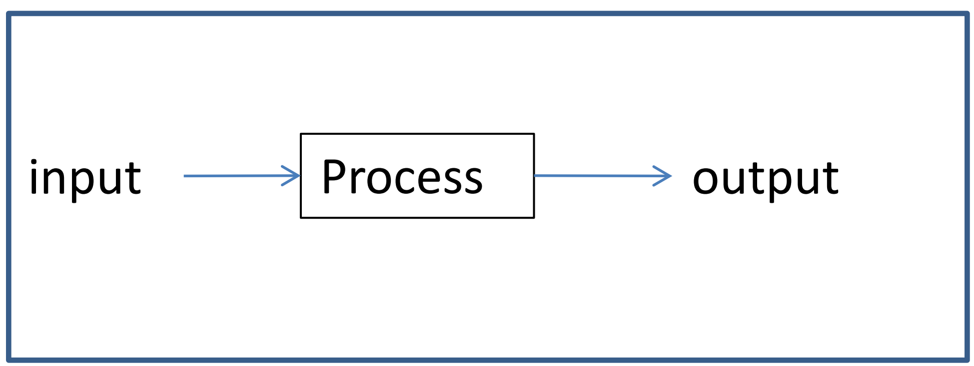


Temperature
I want
Compare
Heater
switch
Fire
Heat
Room
Current temperature

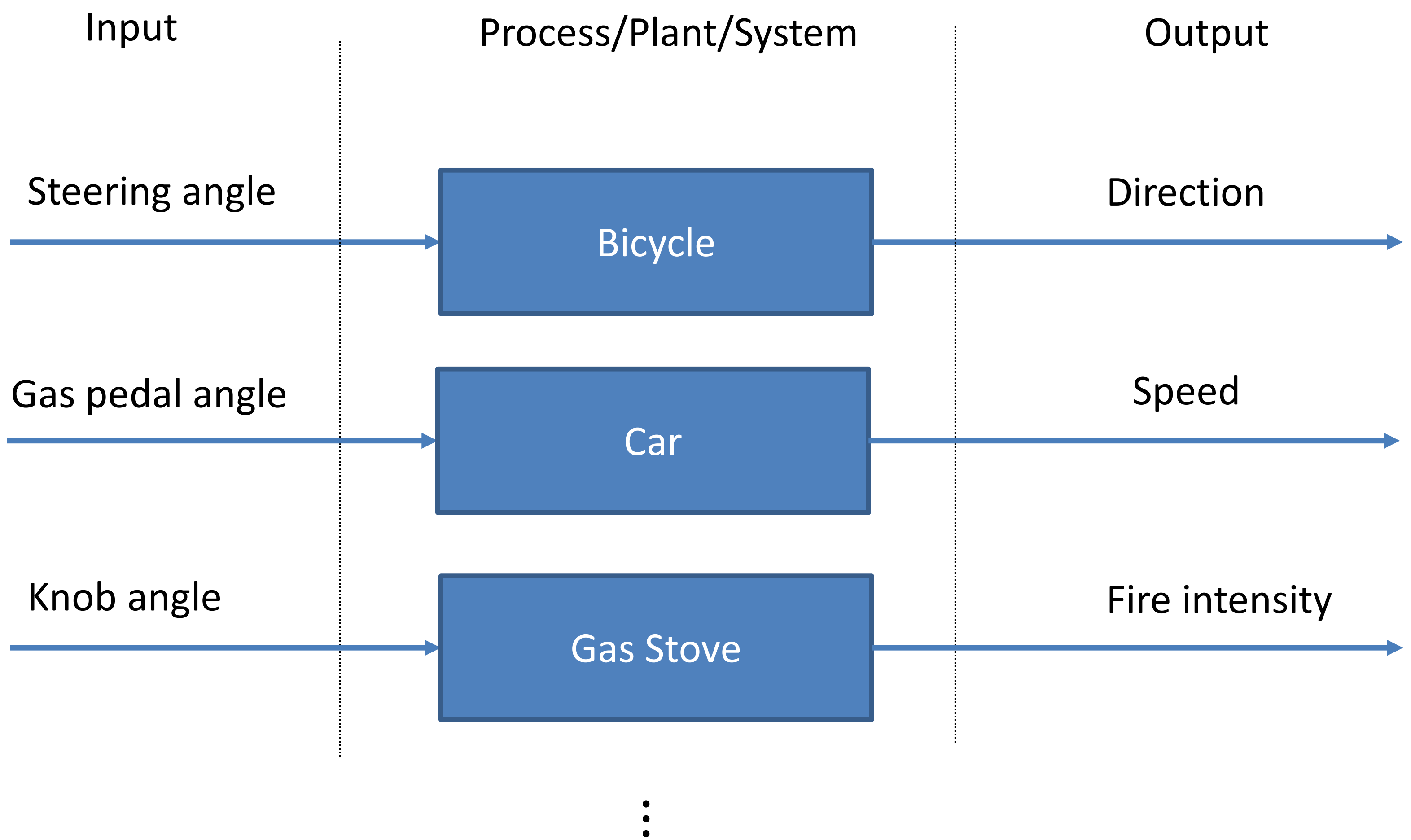
Introduction

- A **control system** is an interconnection of components forming a system configuration that will provide a **desired system response**

- A block diagram represents process or components with blocks

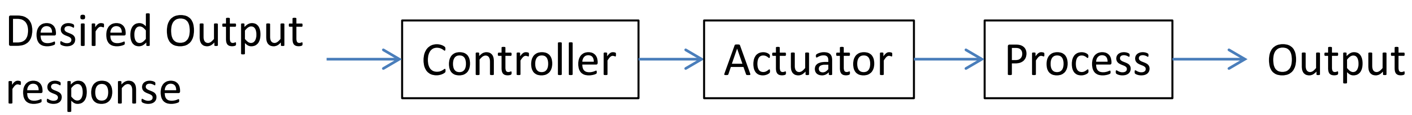


Examples


Input
Process/Plant/System
Output
Steering angle
Bicycle
Direction
Gas pedal angle
Car
Speed
Knob angle
Gas Stove
Fire intensity
⋮

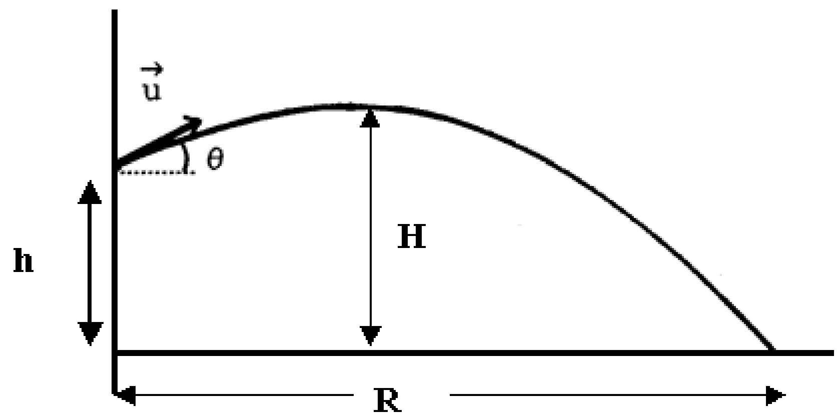
Open Loop

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



Open Loop

- Throwing a ball

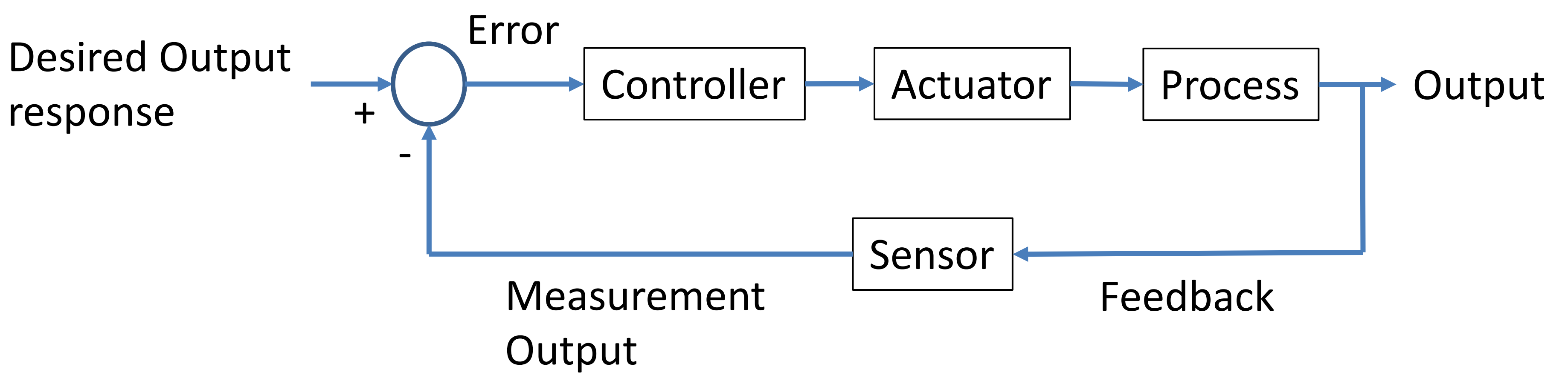


Horizontal motion: uniform motion
Vertical motion: uniformly accelerated motion

- Once the ball leaves your hand, there is no means to correct the trajectory

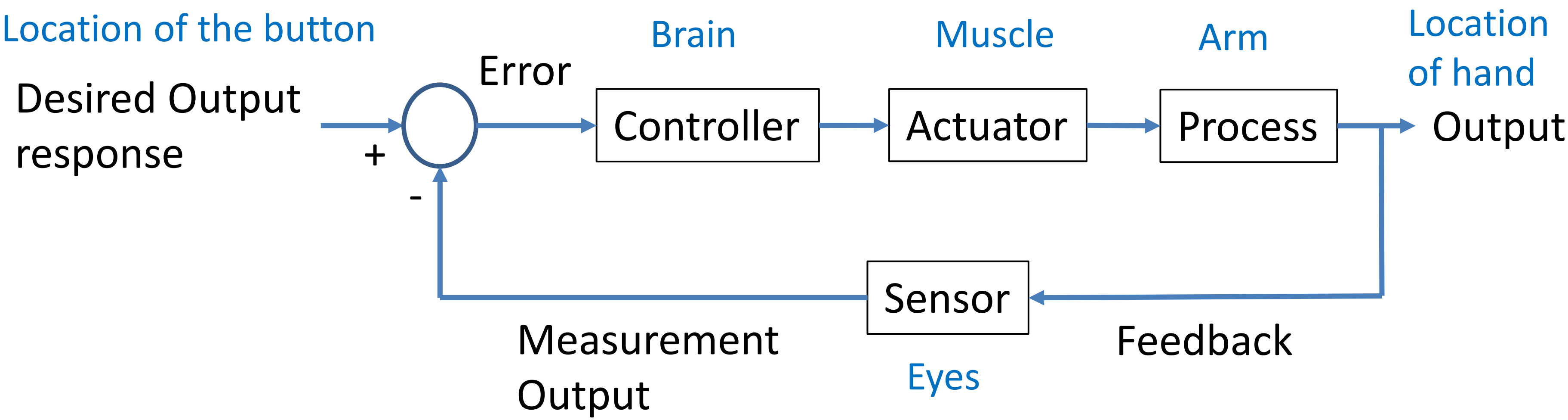
Closed Loop

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

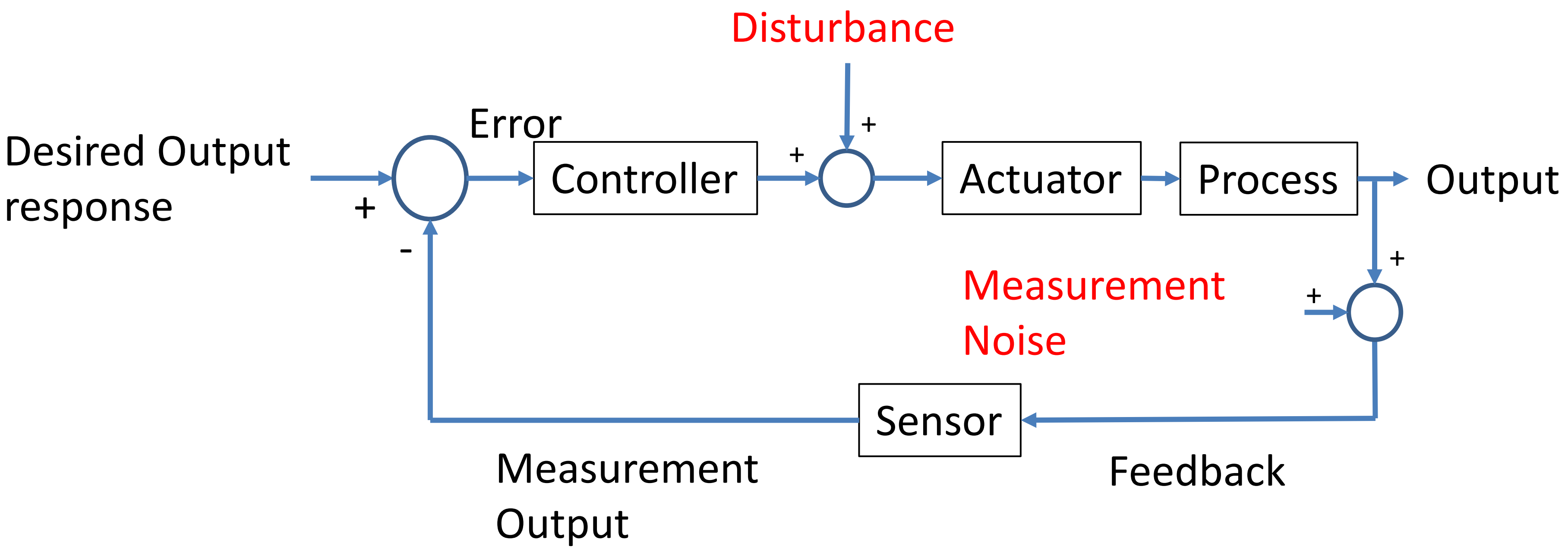


Closed Loop

- Human control system – Pressing a button



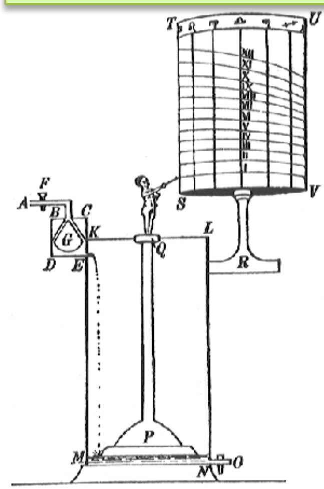
Power of Feedback

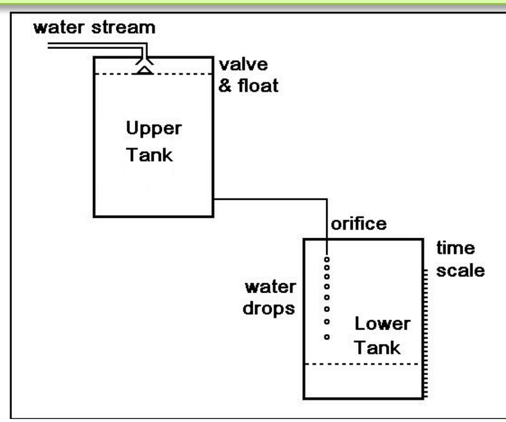


History of Automatic Control

Float Regulator in Greece (300 ~ 1 BCE): water clock, oil lamp

Ktesibios (Ctesibius, Tesibius, 285-222 BCE)

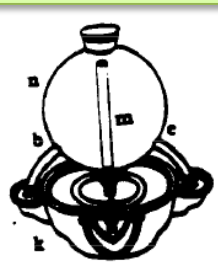


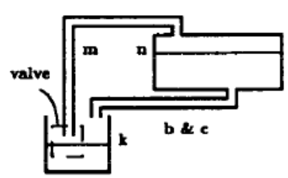


Heron (10-70 CE) wrote *Pneumatica.*

Cornelis Drebbel (1572-1633) invented temperature regulator.

Philon's Oil Lamp (280-220 BCE)





Dennis Papin(1647-1712) invented pressure regulator (cooker).

History of Automatic Control

- James Watt's flyball governor (1769)
  - 1st automatic controller used in an industrial process
  - Beginning of the industrial revolution in UK

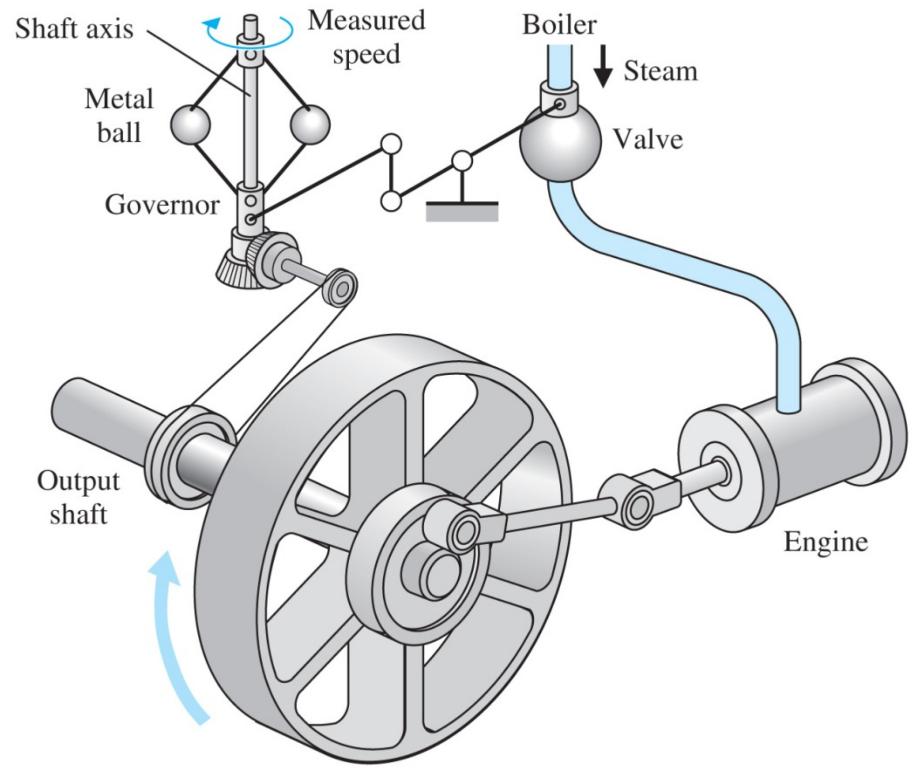
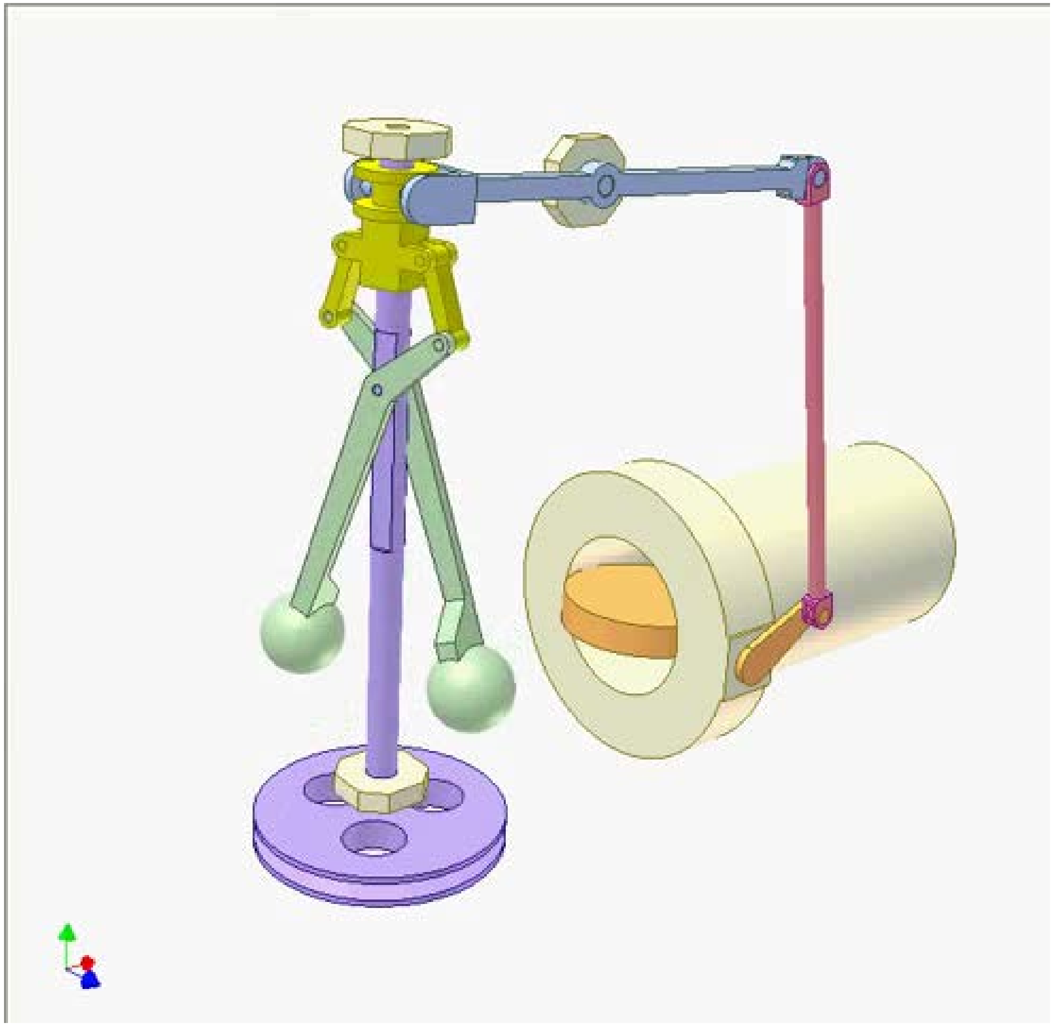


Figure: 01-05

Flyball Governor



History of Automatic Control

- G. B. Airy (1840)
  - Built speed control for telescope using pendulum governor
  - Discovered instability
  - Analyzed the feedback control system using differential equations
- J. C. Maxwell (1868)
  - Developed linearized differential equation around equilibrium
  - Stability – roots of the characteristic equation
- E. J. Routh (1877)
  - Generalized stability criterion

History of Automatic Control

- A. M. Lyapunov (1893)
  - Study on stability
- H. Nyquist (1932), H. W. Bode (1945)
  - Frequency response
- Callendar et al. (1936)
  - PID control
- W. R. Evans (1947)
  - Root locus
- After 1970s
  - Modern control

Examples of Control Systems

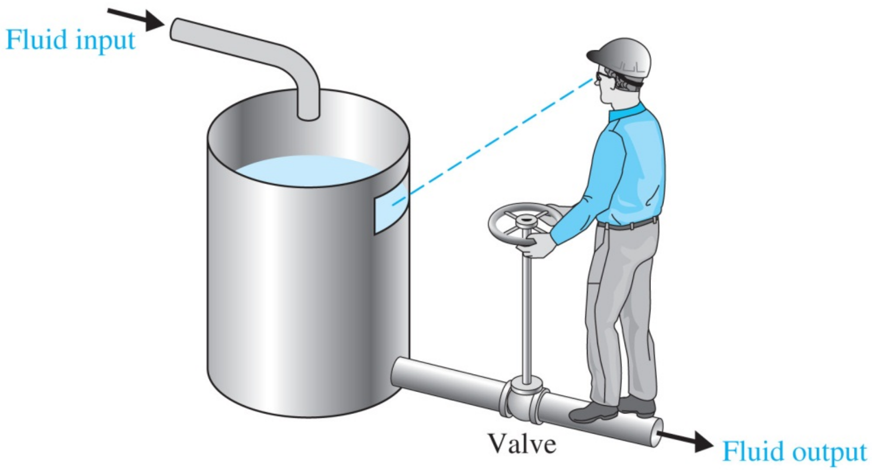


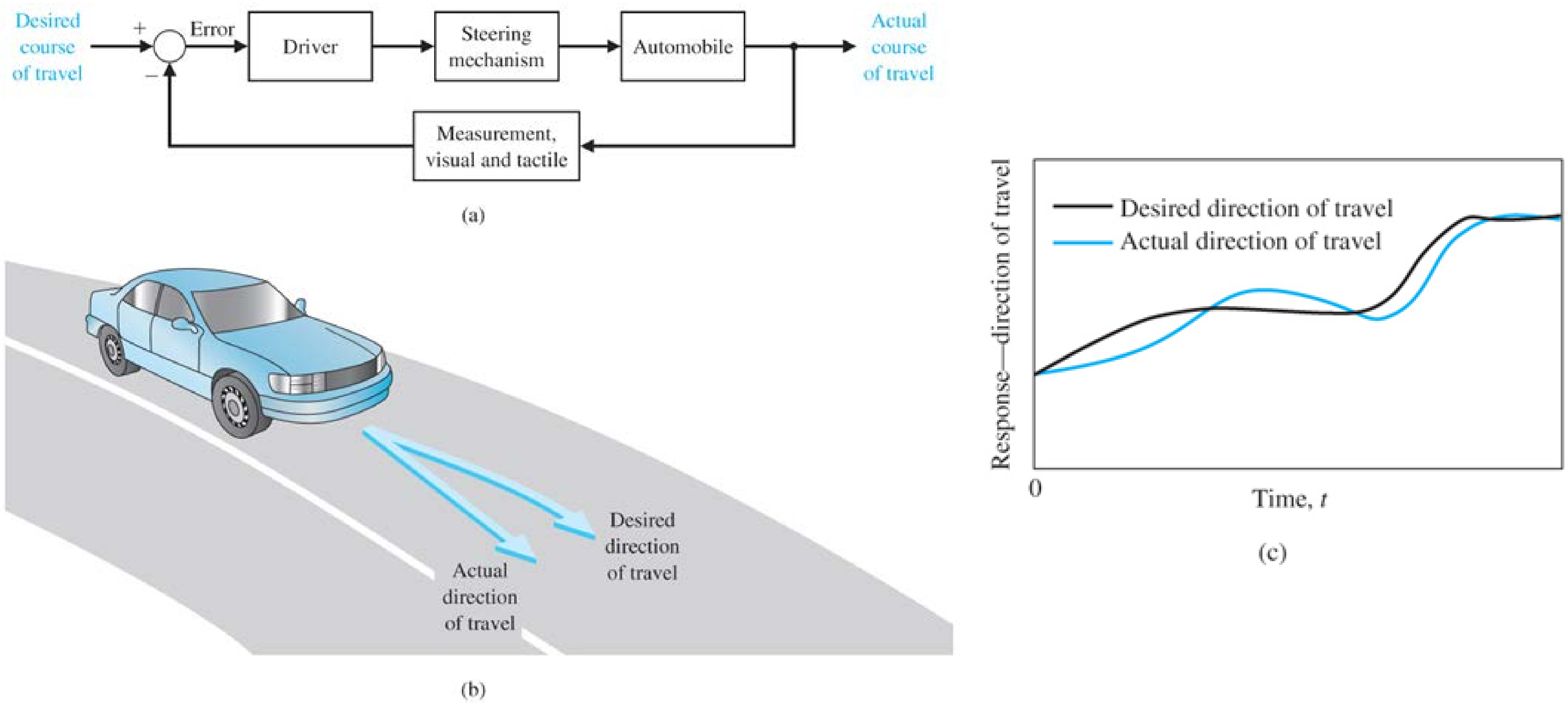
Figure: 01-08

Manual control system water level

Honda Asimo

Tasks Difficult for a Machine	Tasks Difficult for a Human
• Inspect seedlings in a nursery • Drive a vehicle through rugged terrain • Identify the most expensive jewels on a tray of jewels	• Inspect a system in a hot, toxic environment • Repetitively assemble a clock • Land an airliner at night, in bad weather

Examples of Control Systems



Automobile Steering Control System

Examples of Control Systems

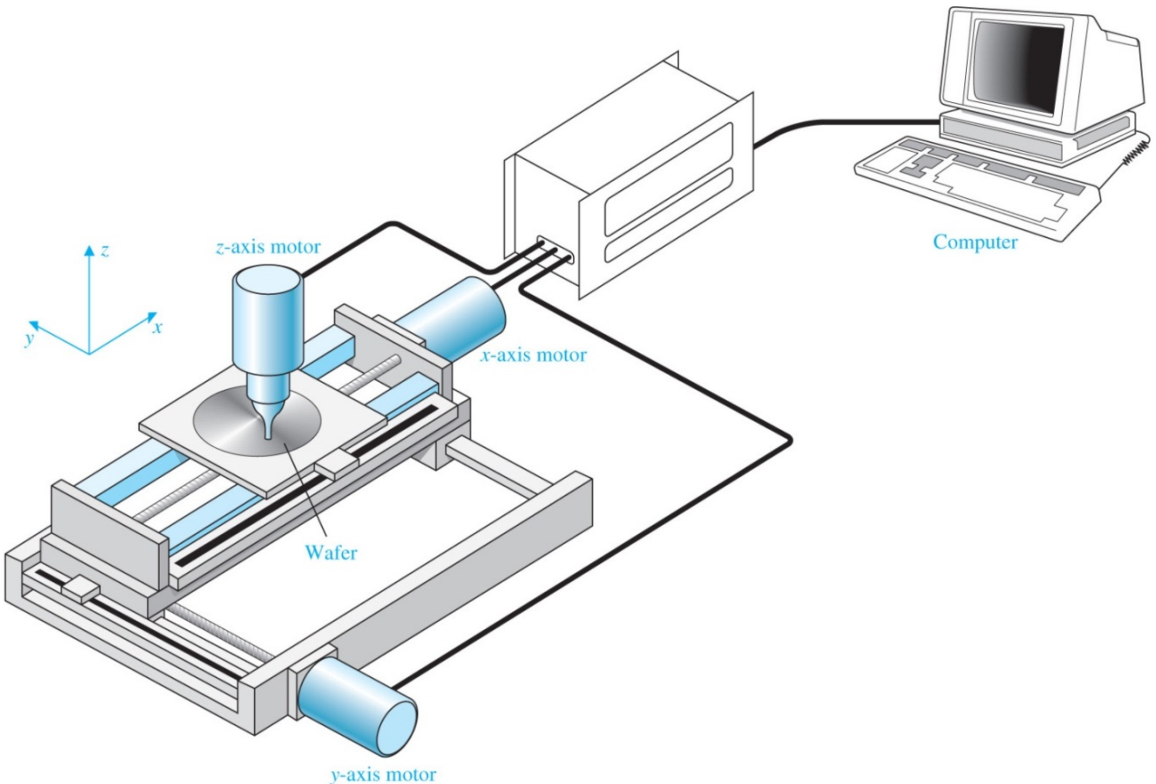


Figure: 01-10

A three-axis control system for inspecting individual semiconductor wafers with a highly sensitive camera

Examples of Control Systems

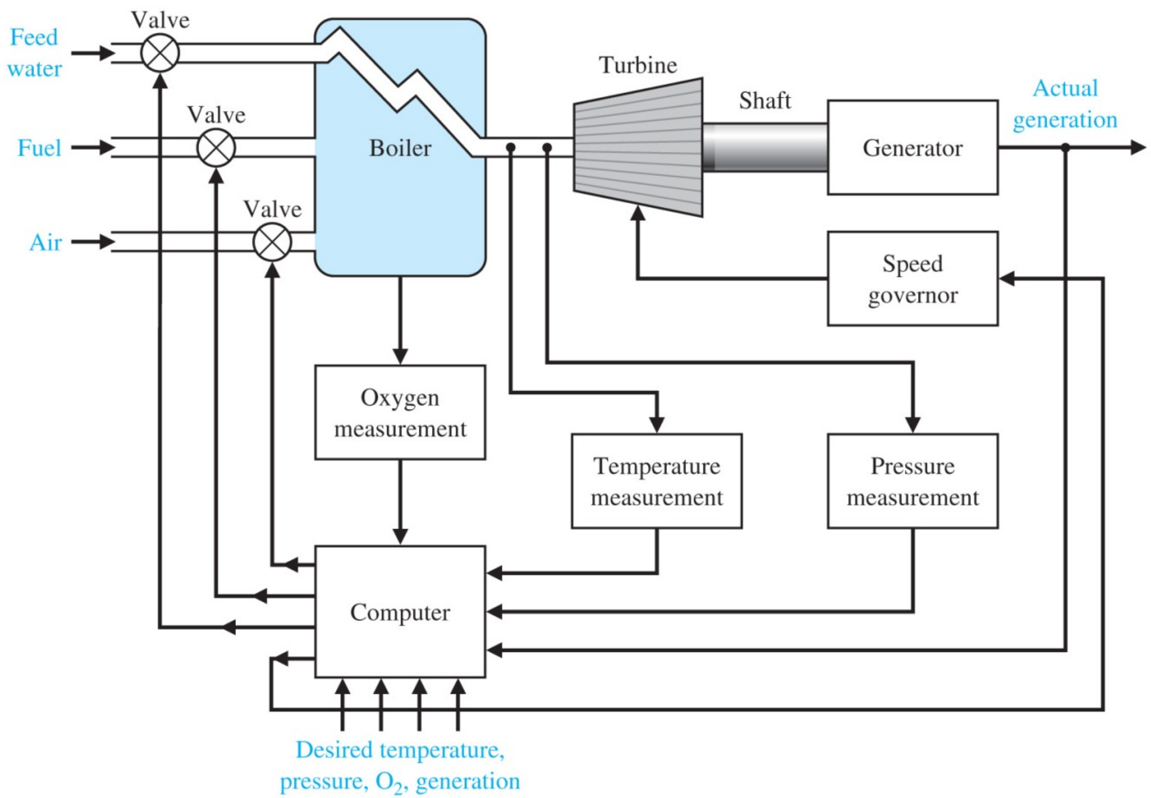
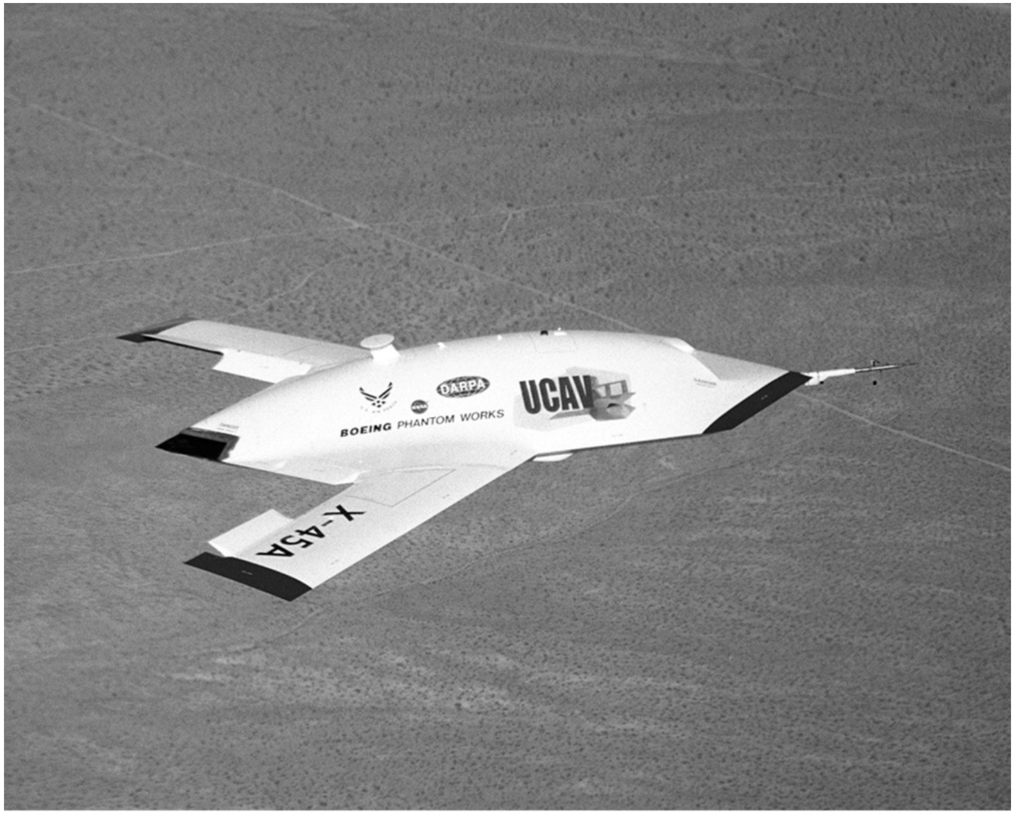


Figure: 01-11

Coordinated control system for a boiler-generator

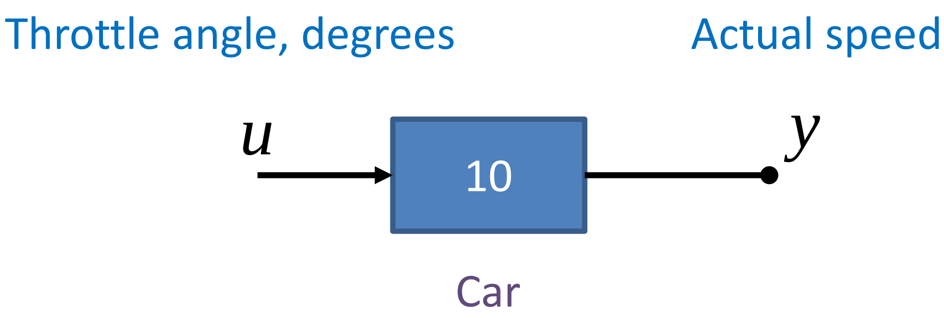
Examples of Control Systems



An unmanned aerial vehicle

A Mathematical Model for Cruise Control

- Open loop
- No disturbance



$$y = 10u$$

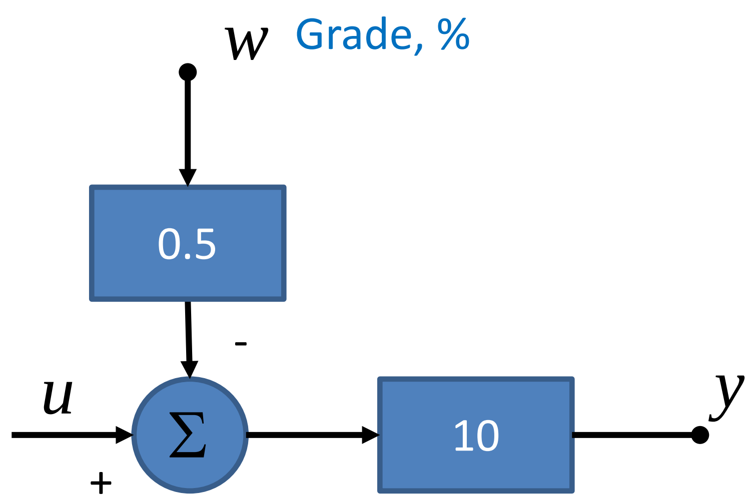
In a Perfect World

- If you want to drive at 60 mph

$$y = 60 \qquad\qquad u = \frac{1}{10}60 = 6$$

- All you have to do is set your throttle angle at 6 degrees

Open Loop with Different Grade



$$y = 10(u - 0.5w)$$

The Road Is Not Always Flat

- You still want to go at 60 mph
  - You set your throttle angle at 6 degrees
- The road happened to have 2% grade

$$y = 10(u - 0.5w)$$

$$10(6 - 0.5 \times 2) = 50$$

- You end up going at 50 mph
  - *What would you do?*

What Would You Do?

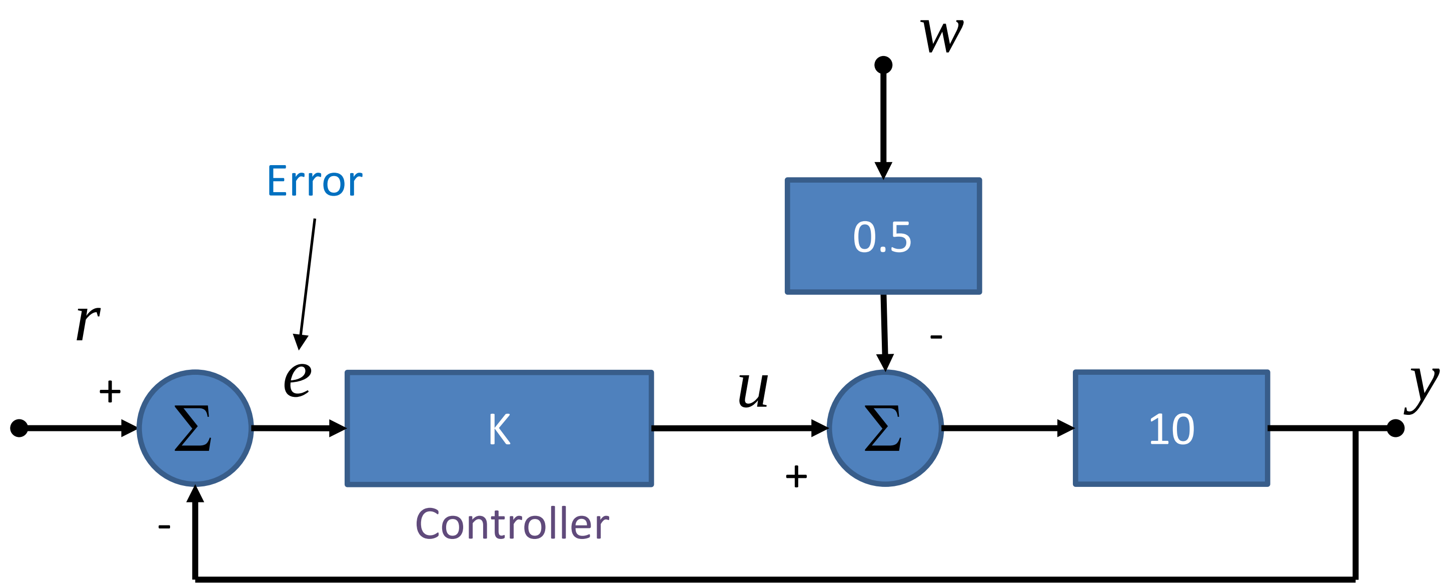
- Measure the grade ?
  - You get out of the car and measure the grade $w = 2$
  - Since you want to drive at 60 mph $y = 60$
  - From
$$y = 10(u - 0.5w)$$
$$60 = 10(u - 0.5 \times 2)$$
$$u = 7$$
  - You set your throttle angle at 7 degrees
- Do you really want to get out of the car?
- What if the grade changes?

What Do You WANT to Do?

- Look at the speed**o**meter
  - If I am going slower than 60 mph, increase the throttle angle
  - If I am going faster than 60 mph, decrease the throttle angle

- Let’s construct this logic as a block diagram

Closed Loop



$$y = 10(u - 0.5w)$$

$$e = r - y$$

$$u = Ke$$

Effects of Feedback

$$y = 10(u - 0.5w) = 10(Ke - 0.5w) = 10(K(r - y) - 0.5w)$$

$$y = \frac{10K}{10K+1} r - \frac{5}{10K+1} w$$

Close to 1
- Follows the reference input

Small
- Rejects disturbances

Observations

- Feedback control significantly reduced the sensitivity to disturbances
- The larger the gain
  - The closer the output is to the input
  - The smaller the sensitivity of the output to the disturbances
- However, the output is not exactly the same as the input
  - Steady-state error