Lecture by

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Instructor and Researcher

Introduction to Automatic Control

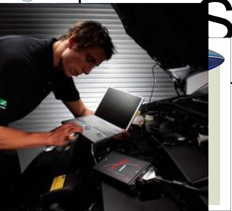
Chapter One

week1

Control Engineering

Reference Book

- "Modern Control Engineering", Katsuhiko Ogata, Prentice Hall.
- "Automotive Control Systems for Engine, Driveline and Vehicle", U.Kiencke and L.Nielsen, Springer.
- "Stabilization and Regulation of Nonlinear Systems. A Robust and Adaptive Approach" Zhiyong Chen • Jie Huang. 2014.
- Khalil H (2002) Nonlinear systems. Prentice Hall, New Jersey
- Isidori A (1999) Nonlinear control systems, 3rd edn. Springer, New York

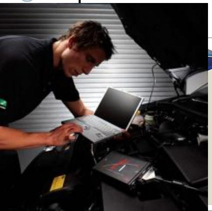


Control Engineering

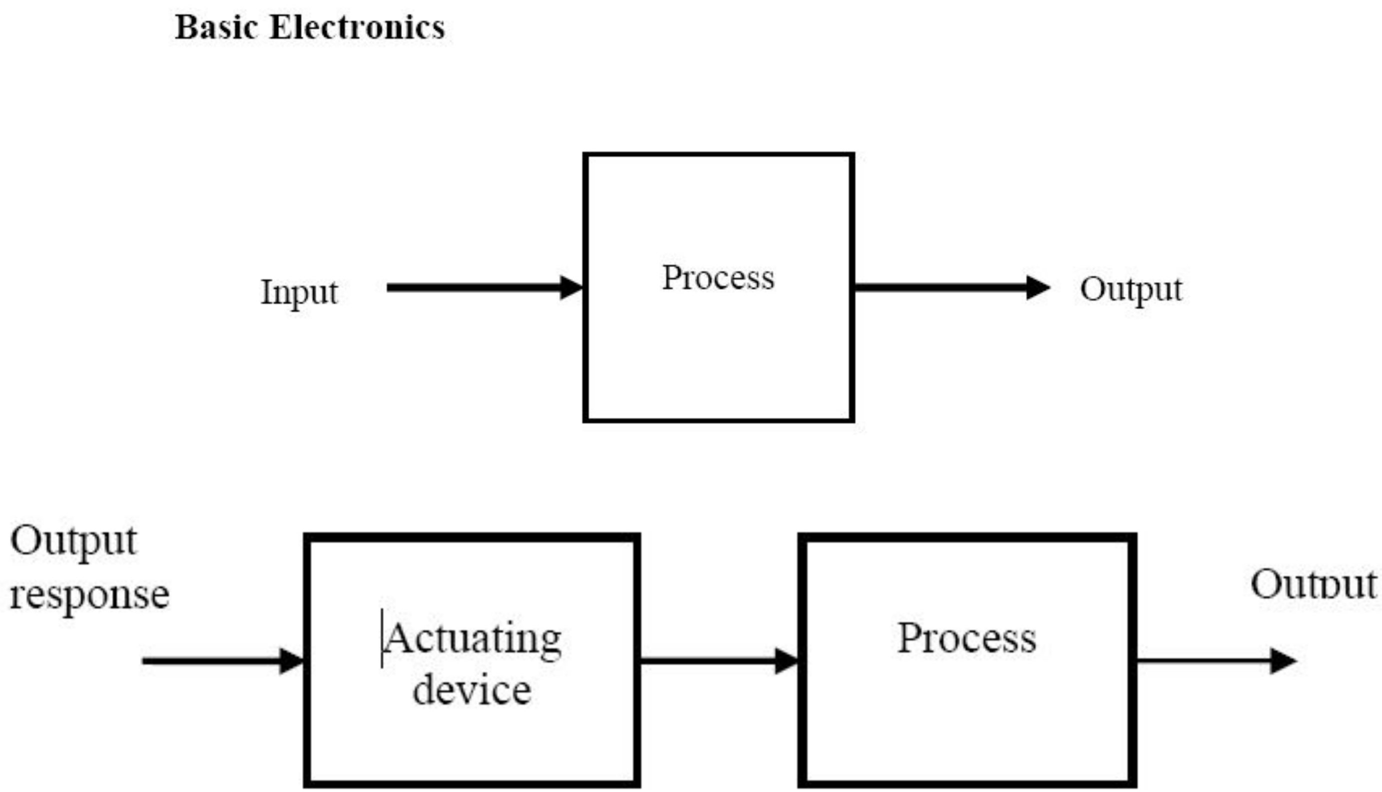
How is it important?

Good Improved control is a key enabling technology underpinning:

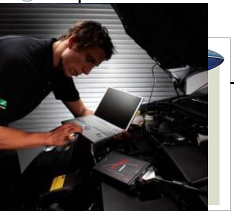
- generally
    - Convenience and Comfort
- doctor
    - Precision of tools
- industry
    - Enhance product quality
        - Waste minimization
        - Higher safety margins



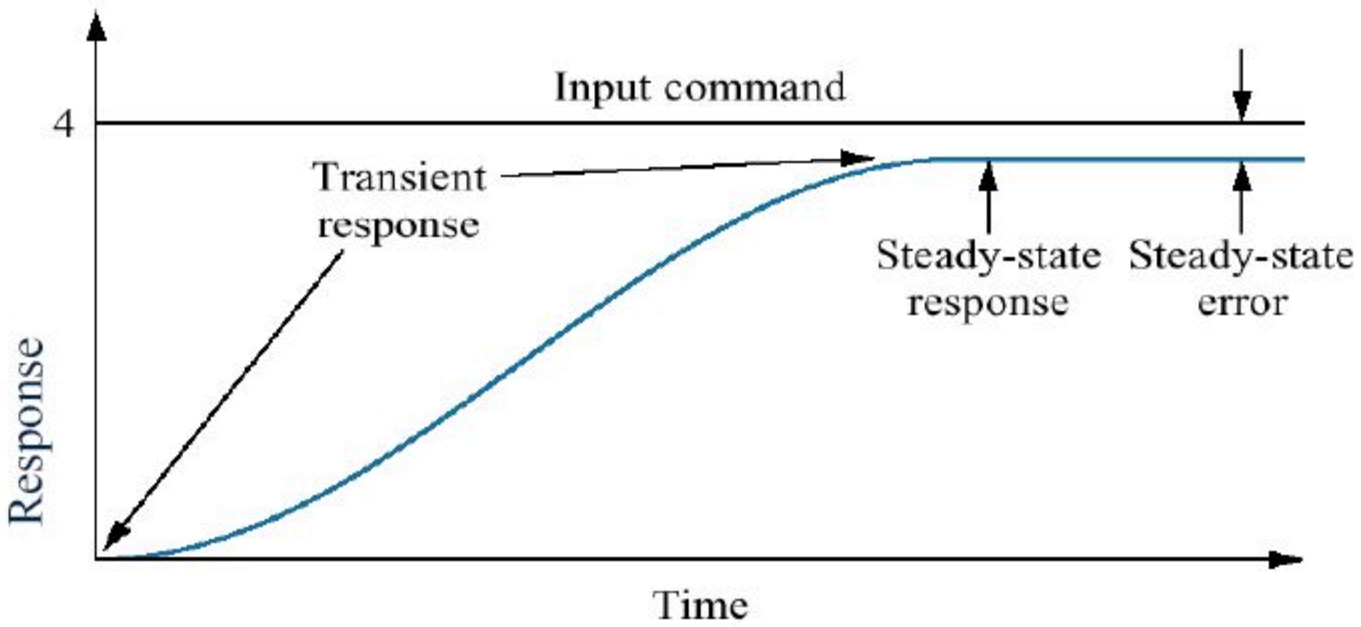
What is Control System?



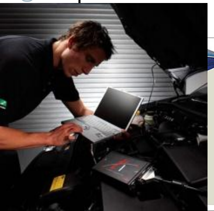
Open-Loop Control System (No feedback)



What is Control System? (2)



Dynamic Response Open-Loop Control System (No feedback)



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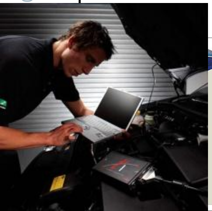
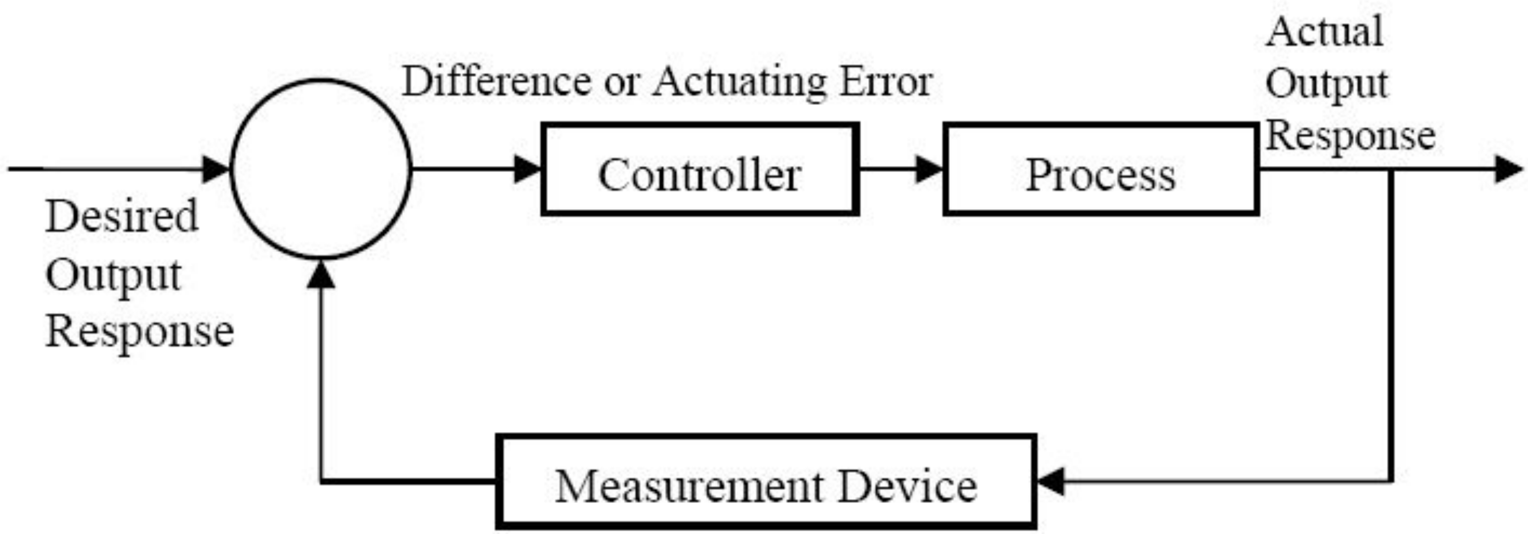
What is Control System? (3)

Feedback

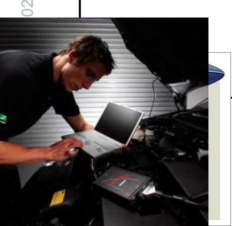
- Feedback is a key tool that can be used to modify the behavior of a system.
- This behavior altering effect of feedback is a key mechanism that control engineers exploit deliberately to achieve the objective of acting on a system to ensure that the desired performance specifications are achieved.



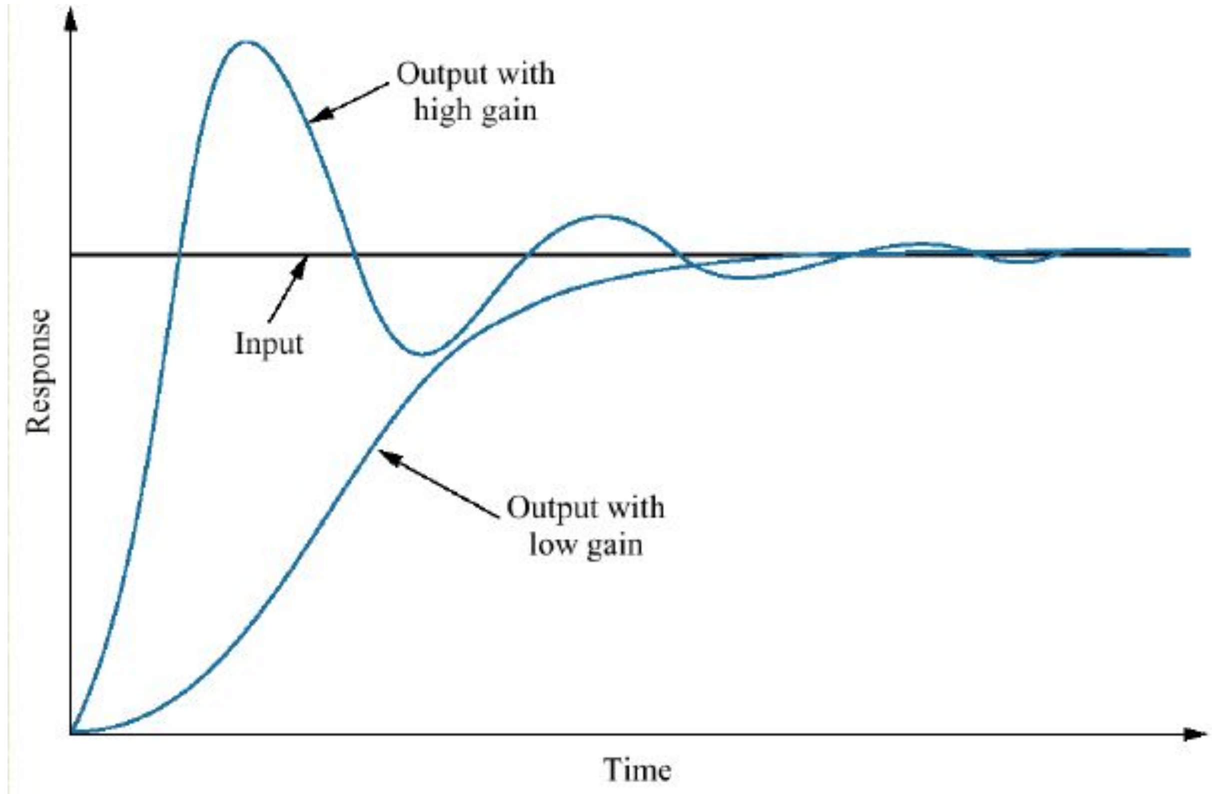
What is Control System? (4)



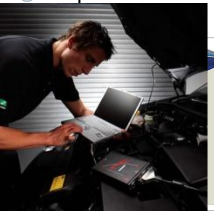
Closed-Loop Control System (No feedback)



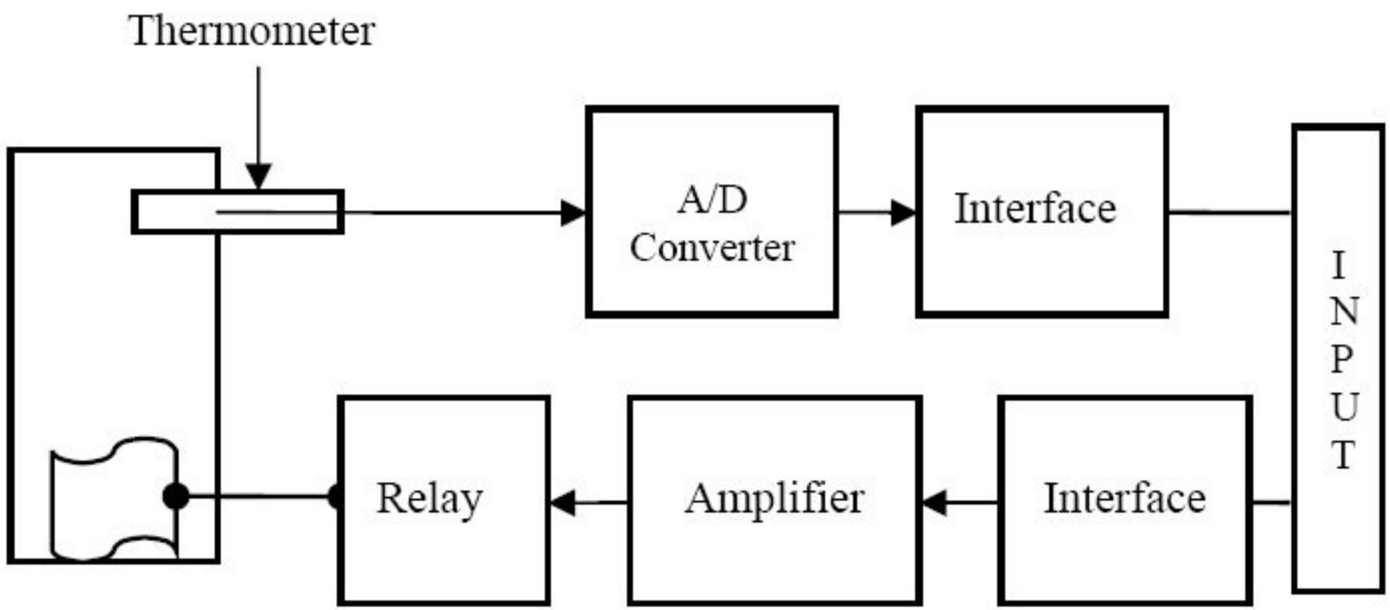
What is Control System? (5)



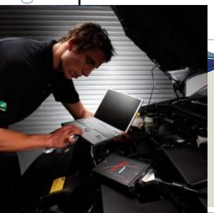
Response of a position control system showing effect of high and low controller gain on the output response



Example Control System? (1)



Temperature Control System (Heater or Air Condition)



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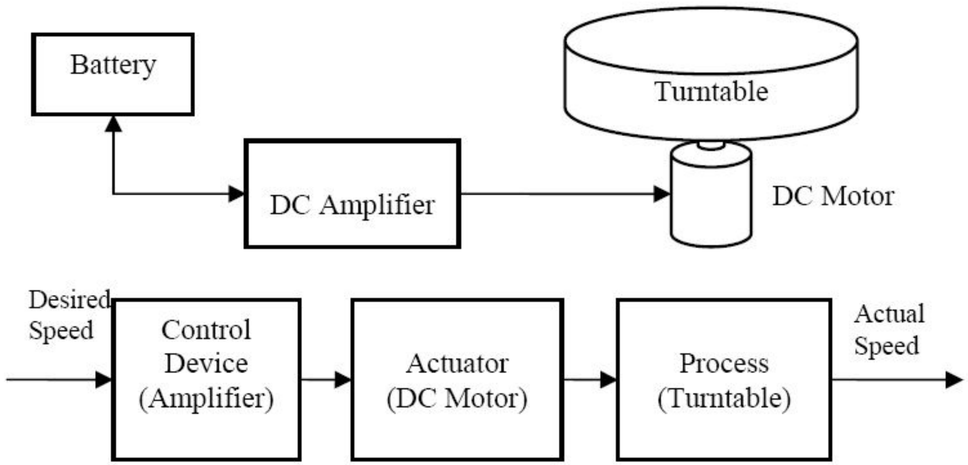
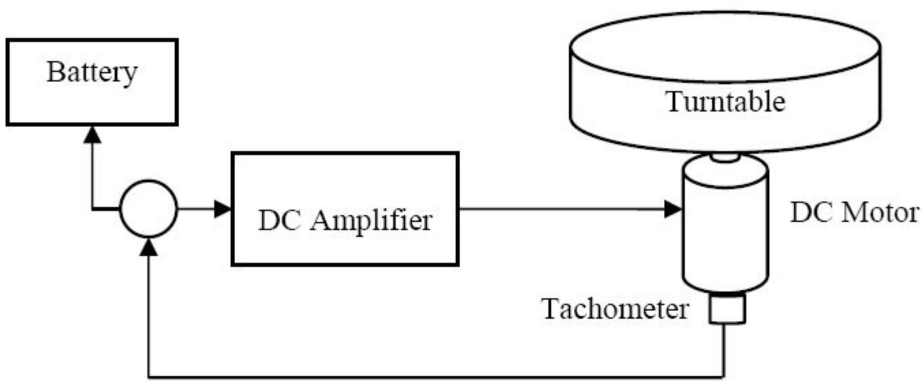
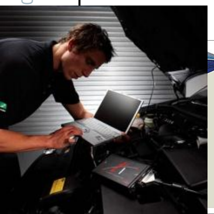
Example Control System? (2)



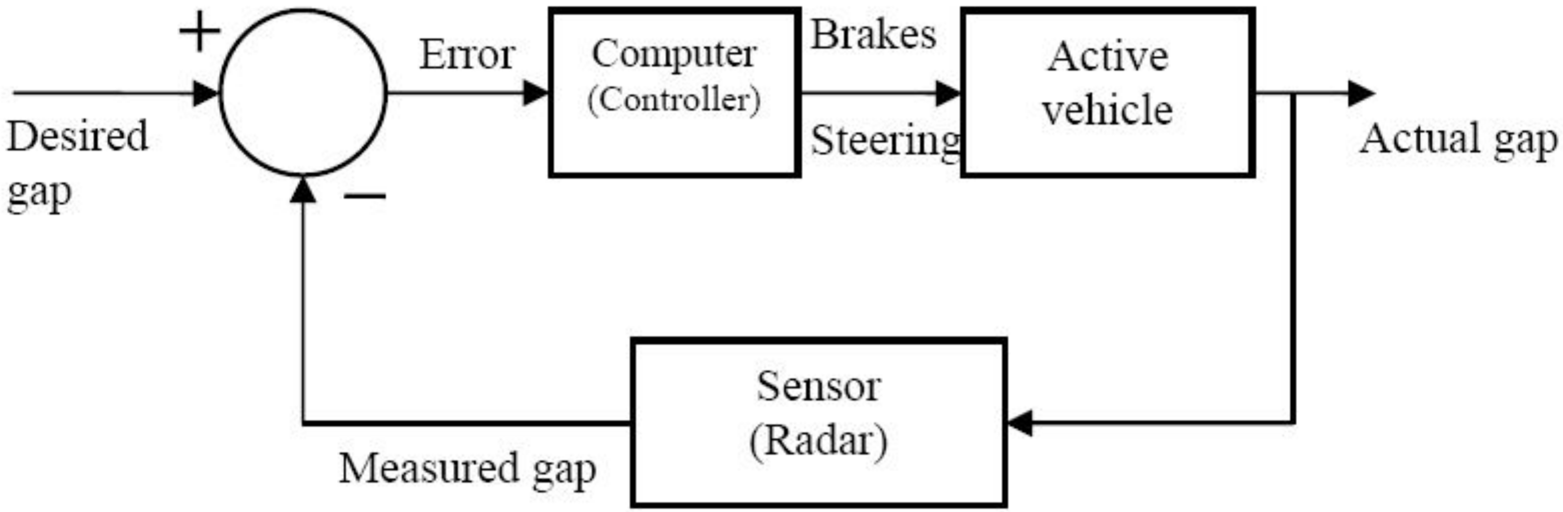
Open Loop



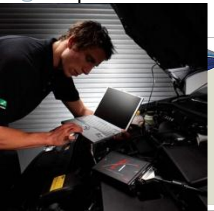
Closed Loop



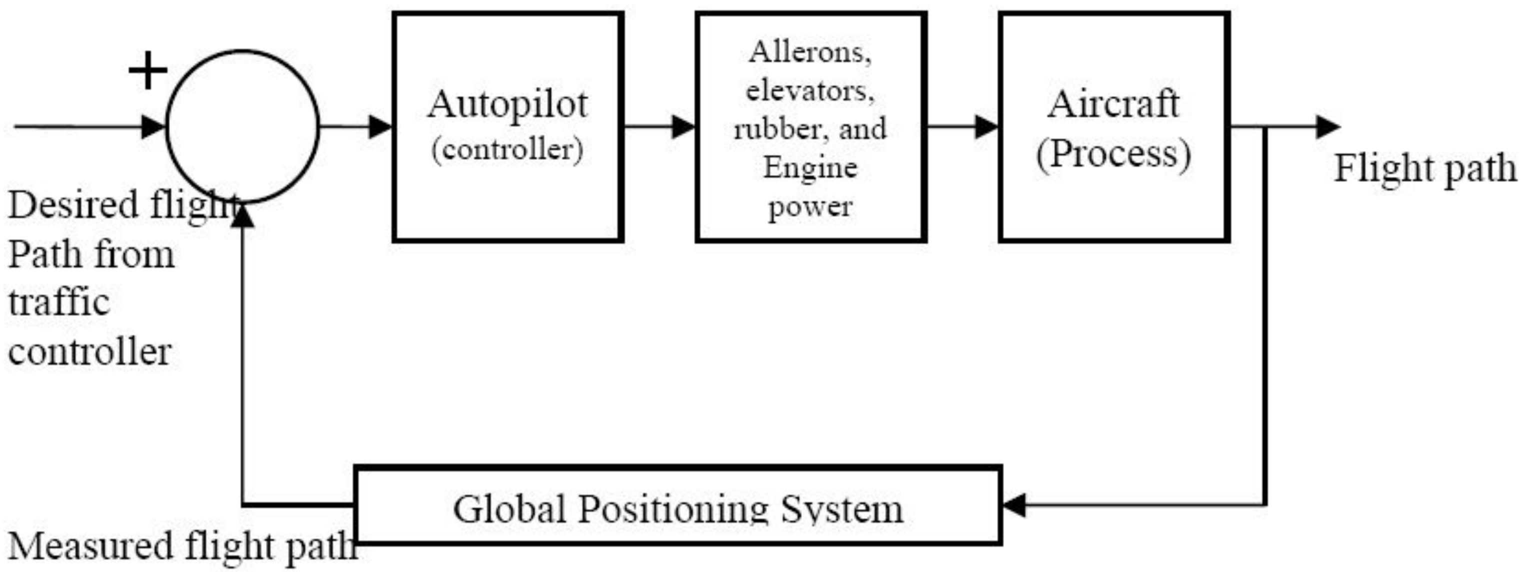
Example Control System? (3)



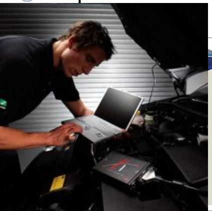
Vehicle Control System



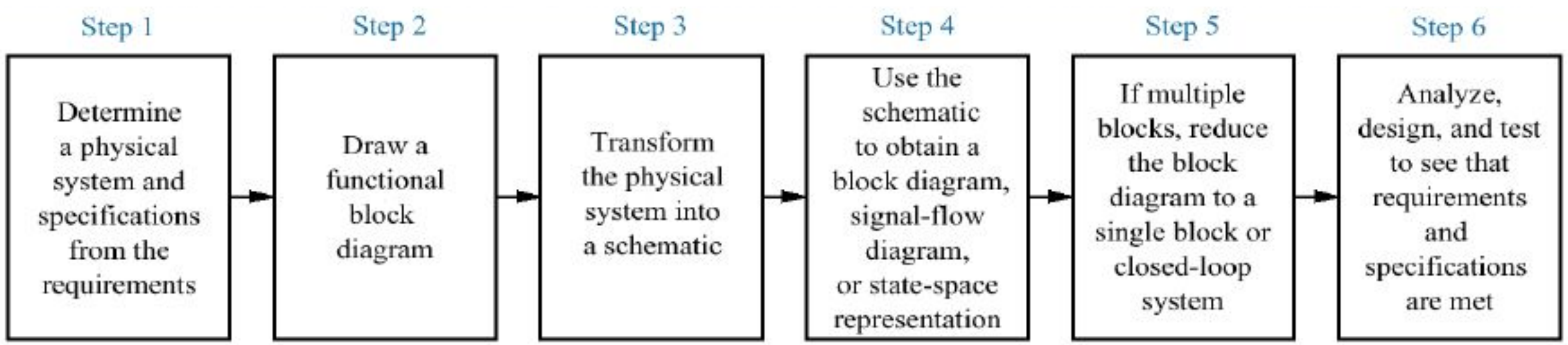
Example Control System? (4)

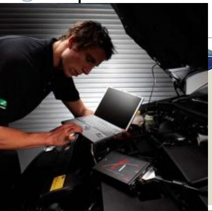


Autopilot Control System



Control System Design Cycle





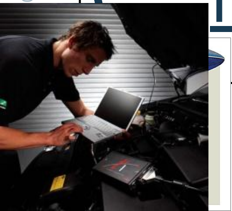
Modeling & Design in Control

I. DYNAMIC MODELING

- Deriving a dynamic model (= set of differential equations that describes the dynamic behavior of the plant)
- Linearization the dynamic model if necessary

II. DESIGN OF A CONTROLLER: Several design methods

1. Classical control or Root Locus Design:
   Define the transfer function; Apply root locus, loop shaping,
2. Modern control:
   Convert ODE to state equation; Apply Pole Placement, Robust control, …
3. Nonlinear control: Apply Lyapunov's stability criterion



Control Engineering

Definition of state space representations

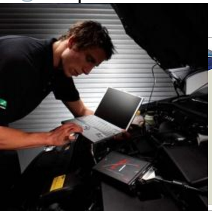
A **continuous-time** LINEAR state space system is given as :

$$\begin{cases} \dot{x}(t) = A(x(t) + Bu(t), \quad x(0) = x_0 \\ y(t) = Cx(t) + Du(t) \end{cases} \qquad (2)$$

- $x(t) \in \mathbb{R}^n$ is the system state (vector of state variables),
- $u(t) \in \mathbb{R}^m$ the control input
- $y(t) \in \mathbb{R}^p$ the measured output
- A, B, C and D are real matrices of appropriate dimensions
- x_0 is the initial condition.

n is the order of the state space representation.

Matlab : ss(A,B,C,D) creates a SS object SYS representing a continuous-time state-space model



Control Engineering

A first example of Modeling: DC Motor

The dynamical equations are :

$$Ri + L\frac{di}{dt} + e = u \qquad e = K_e\omega$$

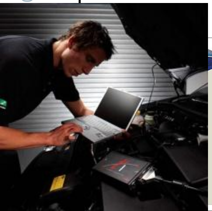
$$J\frac{d\omega}{dt} = -f\omega + \Gamma_m \qquad \Gamma_m = K_c i$$

System of 2 equations of order 1 $\Longrightarrow$ 2 state variables.

A possible choice $x = \begin{pmatrix} \omega \\ i \end{pmatrix}$ It gives:

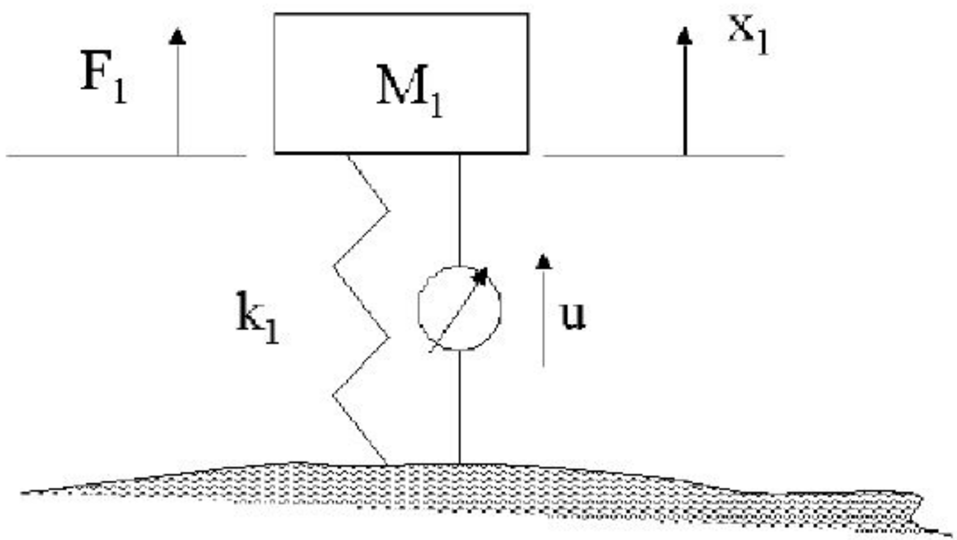
$$A = \begin{pmatrix} -f/J & K_c/J \\ -K_e/L & -R/L \end{pmatrix} B = \begin{pmatrix} 0 \\ 1/L \end{pmatrix} C = \begin{pmatrix} 0 & 1 \end{pmatrix}$$

Extension: measurment= motor angular position



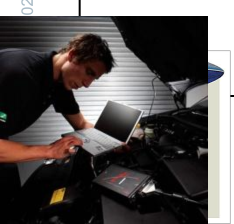
A second example of Modeling: Suspension

Let the following mass-spring-damper system.



where x_1 is the relative position, M_1 the system mass, k_1 the spring coefficient, u the force generated by the active damper, and F_1 is an external disturbance. Applying the mechanical equations it leads:

$$M_1 \ddot{x}_1 = -k_1 x_1 + u + F_1 \qquad (3)$$



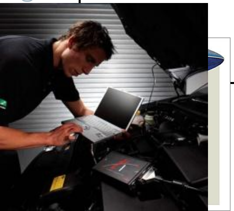
A second example of Modeling: Suspension (2)

The choice $x = \begin{pmatrix} x_1 \\ \dot{x}_1 \end{pmatrix}$ gives

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) + Ed(t) \\ y(t) = Cx(t) \end{cases}$$

where $d = F_1$, $y = x_1$ with

$$A = \begin{pmatrix} 0 & 1 \\ -k_1/M_1 & 0 \end{pmatrix}, \quad B = E = \begin{pmatrix} 0 \\ 1/M_1 \end{pmatrix}, \text{and} \quad C = \begin{pmatrix} 0 & 1 \end{pmatrix}$$



Linear systems : transfer function

- Equivalence transfer function - state space representation

Consider a linear system given by:

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t), \quad x(0) = x_0 \\ y(t) = Cx(t) + Du(t) \end{cases} \tag{6}$$

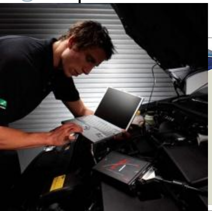
Using the Laplace transform (and assuming zero initial condition $x_0 = 0$), (6) becomes:

$$s.x(s) = Ax(s) + Bu(s) \;\Rightarrow\; (s.I_n - A)x(s) = Bu(s)$$

Then the transfer function matrix of system (6) is given by

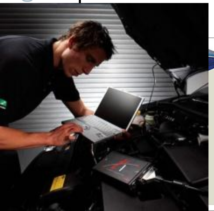
$$G(s) = C(sI_n - A)^{-1}B + D = \frac{N(s)}{D(s)} \tag{7}$$

`Matlab:` *if SYS is an SS object, then* **`tf(SYS)`** *gives the associated transfer matrix. Equivalent to* **`tf(N,D)`**



State-Space Representations of Transfer-Function Systems

Go to Ogata Book 723



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