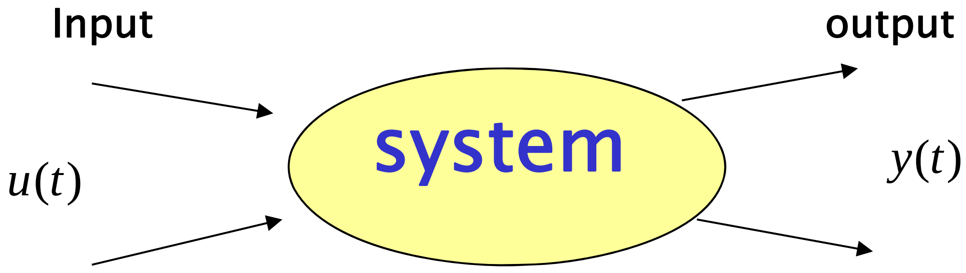
Lecture 12

Control Systems

System, Input and Output



Output depends on inputs !

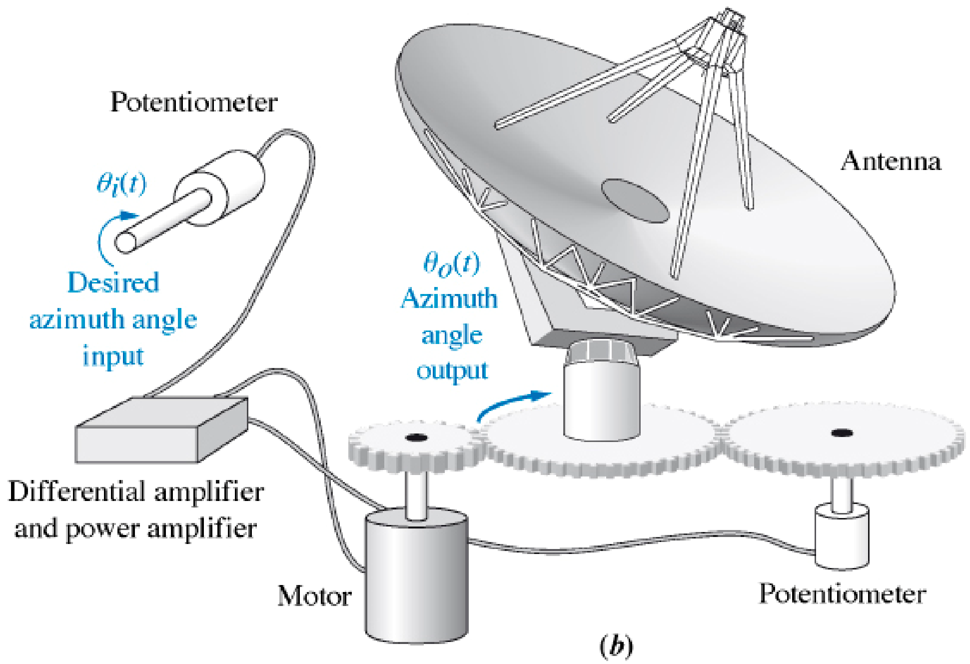
Control systems

Open loop control

Closed loop control

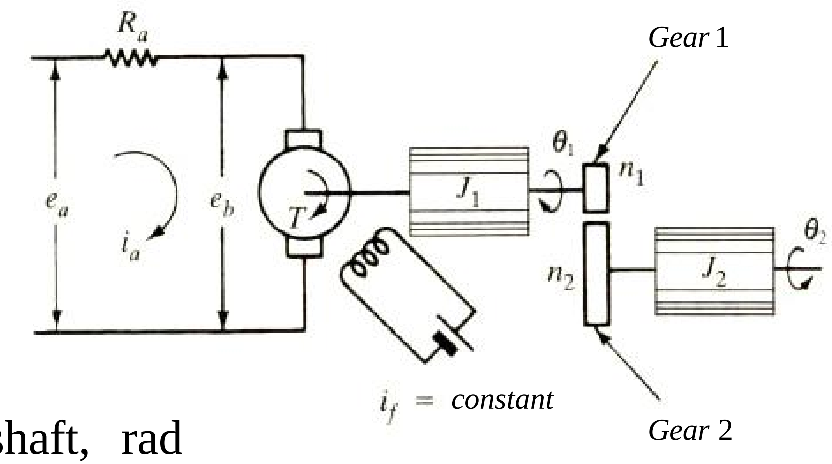
Closed loop transfer function

Antenna azimuth position control system



a DC Servomotor System

servo-motor system



R_a : armature resistance, Ω

i_a : armature current, A

i_f : field current, A

e_a : applied armature voltage, V

e_b : back emf, V

θ_1 : angular displacement of the motor shaft, rad

θ_2 : angular displacement of the load shaft, rad

T : torque developed by the motor, N-m

J_1 : equivalent moment of inertia of the motor, kg-m^2

J_2 : equivalent moment of inertia of the load, kg-m^2

The torque of motor : $T = K i_a$

For a constant flux, the induced voltage : $e_b = K_b \frac{d\theta}{dt}$ K_b : *back emf constant*

DC Servomotor System

Armature circuit D.E : $R_a i_a + e_b = e_a$ Inertia and friction : $J_{1eq} = J_1 + \left(\frac{n_1}{n_2}\right)^2 J_2$

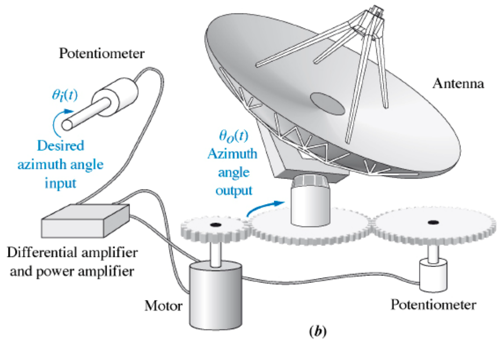
Laplace transforms of these equations :

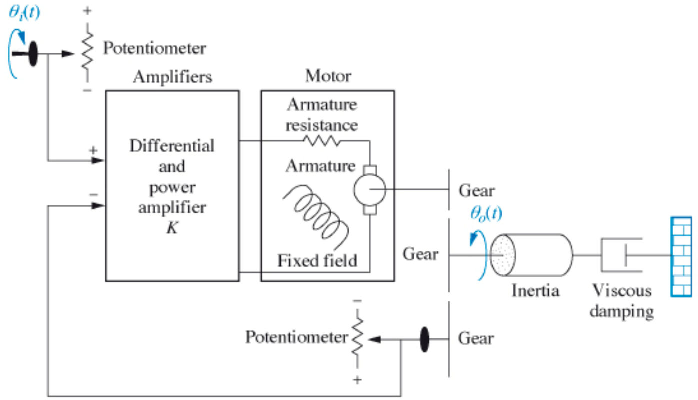
$$K_b s\Theta(s) = E_b(s), \quad (L_a s + R_a)I_a(s) + E_b(s) = E_a(s), \quad (Js^2 + bs)\Theta(s) = T(s) = KI_a(s)$$

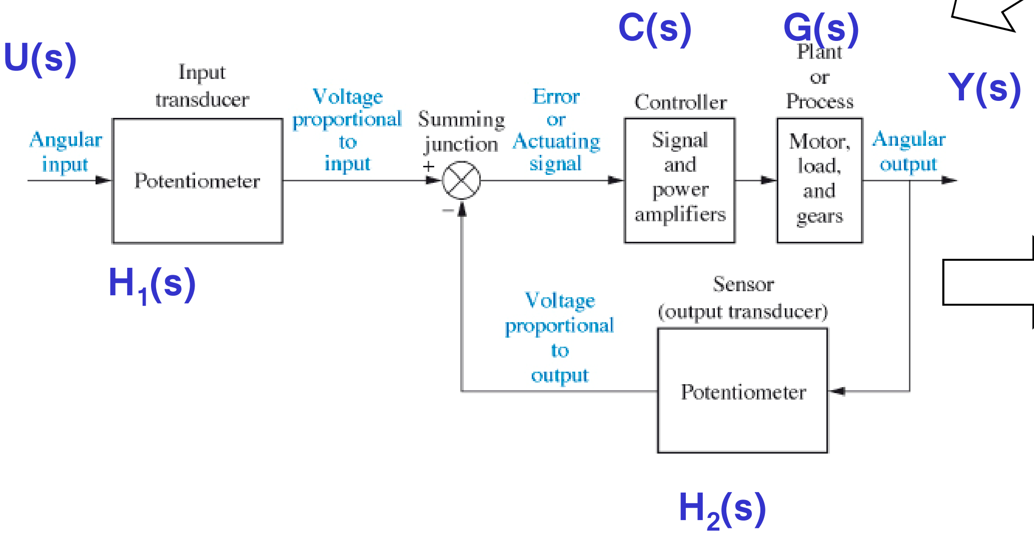
$$T.F = \frac{\Theta(s)}{E_a(s)} = \frac{K}{s(R_a Js + R_a b + KK_b)} = \frac{\frac{K}{R_a J}}{s\left(s + \frac{R_a b + KK_b}{R_a J}\right)}$$

$$= \frac{K_m}{s(T_m s + 1)}$$

System → Schematic → Block Diagram →Transfer Functions



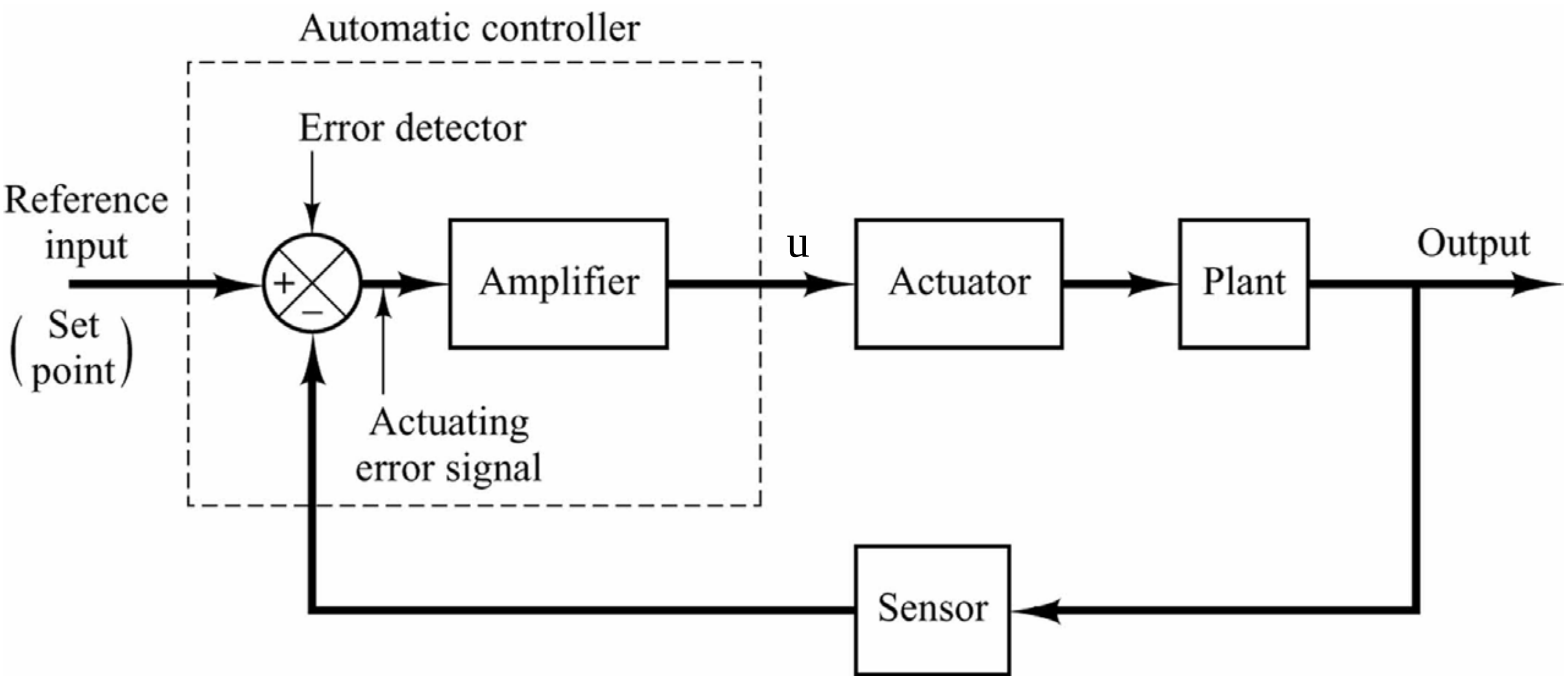




$$Y(s)=\frac{C(s)G(s)H_1(s)}{1+C(s)G(s)H_2(s)}\,U(s)$$

Antenna azimuth position control system

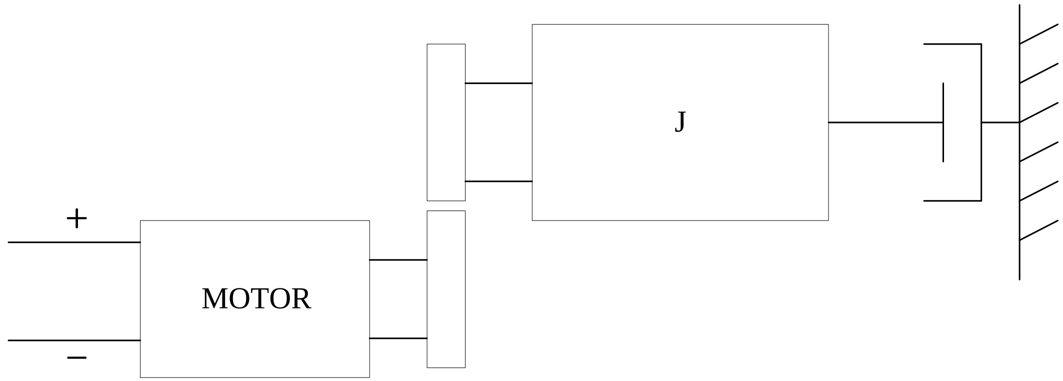
Control Systems

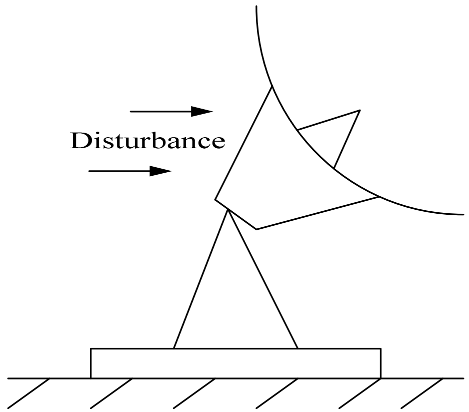


$$u=f(r,c)$$

Proportional Control

$U = k_p e$ k_p : The proportional Gain





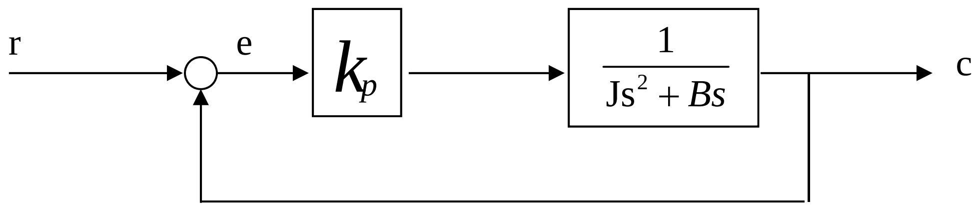
Antenna Position
Control System

Proportional Control

=

$$U = k_p e$$

k_p : The proportional Gain



$$\frac{c(s)}{r(s)} = \frac{\frac{K_p}{Js^2 + Bs}}{1 + \frac{K_p}{Js^2 + Bs}} = \frac{K_p}{Js^2 + Bs + K_p}$$

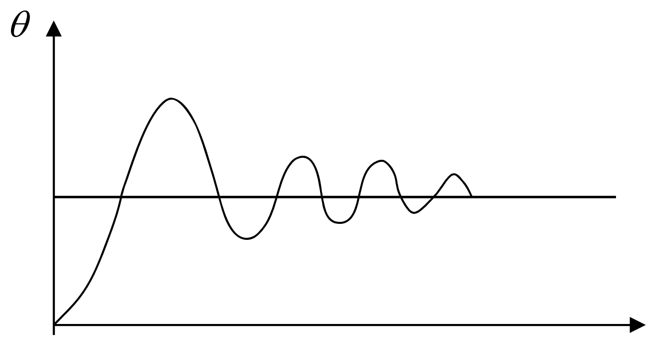
Proportional Control

=

- Step input response $r(s) = \frac{1}{s}$

- steady state response $c(t) = \lim_{s \to 0} sC(s)$

$$= \lim_{s \to 0} s \frac{K_p}{Js^2 + Bs + K_p} \frac{1}{s} = 1$$



Proportional Control

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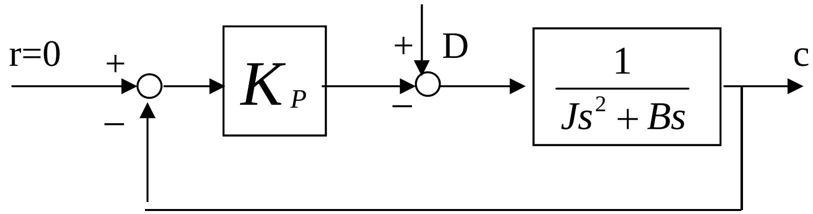
- Response to torque disturbance



$$C(s) = \frac{K_p}{Js^2 + Bs + K_p} r(s) + \frac{1}{Js^2 + Bs + K_p} D(s)$$

Assume that $D(s) = \frac{1}{s}$ steady state response

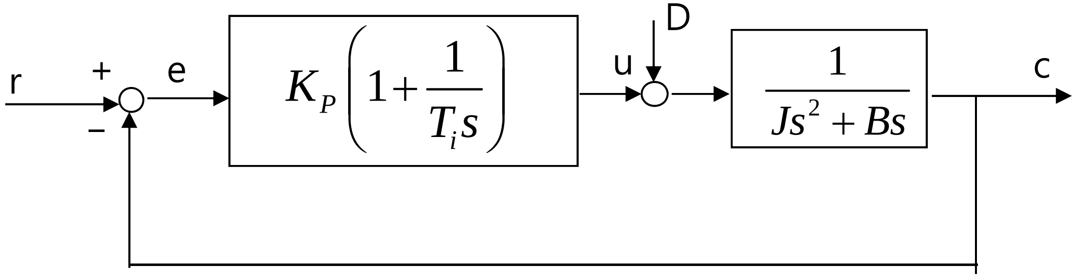
$$c(t) = \lim_{s \to \infty} s \cdot \frac{1}{Js^2 + Bs + K_p} \cdot \frac{1}{s} = \frac{1}{K_p}$$: steady-state error

Large K_p
→ small steady-state error
→ large motor power is needed
→ oscillations
→ large w_n $\left(w_n = \sqrt{\frac{K_p}{J}} \right)$
→ small damping ratio $\zeta = \frac{B}{2\sqrt{JK_p}}$

Proportional-Integral Control (PI control)

- Response to torque disturbance

=



$$\frac{U(s)}{E(s)} = K_P\left(1+\frac{1}{T_i s}\right)$$

$$u(t) = K_p e(t) + \frac{K_P}{T_i}\int_0^t e(t)dt$$

$$\frac{C(s)}{R(s)} = \frac{K_P s + \frac{1}{T_i}K_P}{Js^3 + Bs^2 + K_P s + \frac{K_P}{T_i}}$$

No steady-state error for reference input

Proportional-Integral Control (PI control)

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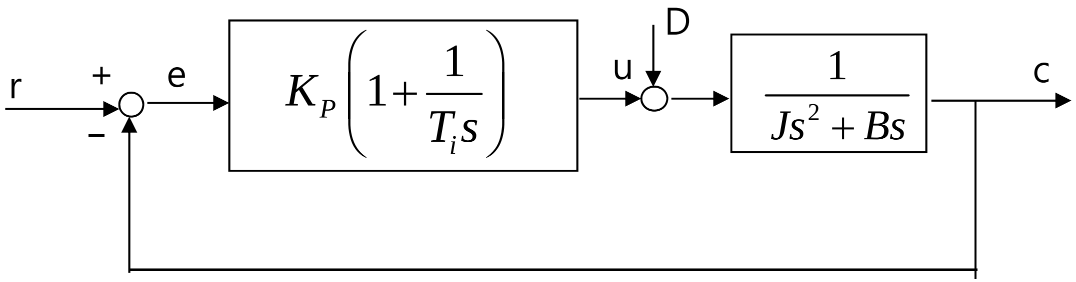

$$\frac{C(s)}{D(s)} = \frac{\frac{1}{Js^2+Bs}}{1+K_P(1+\frac{1}{T_i s})\frac{1}{Js^2+Bs}}$$

$$= \frac{s}{Js^3+Bs^2+K_P s+\frac{K_P}{T_i}}$$

$$D(s) = \frac{1}{s}$$

$$C(t) = \lim_{s\to 0} s\frac{s}{Js^3+Bs^2+K_P s+\frac{K_P}{T_i}}\frac{1}{s} = 0$$

No steady-state error for step disturbance

Proportional-Derivative Control (PD control)

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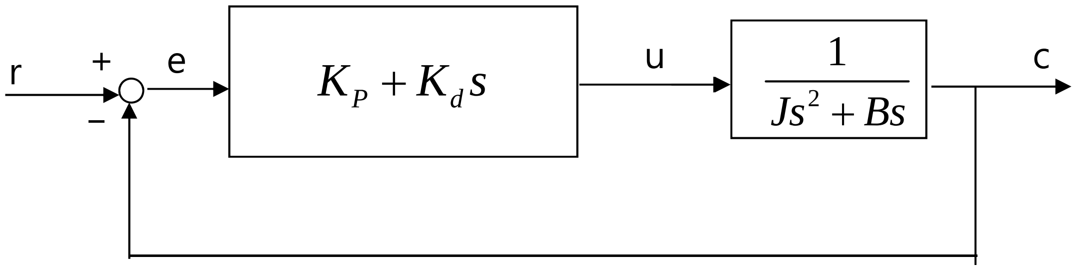

$$u(t) = K_P e(t) + K_d \frac{d}{dt} e(t)$$

$$\frac{C(s)}{R(s)} = \frac{K_P + K_d s}{Js^2 + (B + K_d)s + K_P}$$

$$\zeta = \frac{B + K_d}{2\sqrt{JK_P}}$$: increased effective damping

Proportional-Integral-Derivative Control (PID control)

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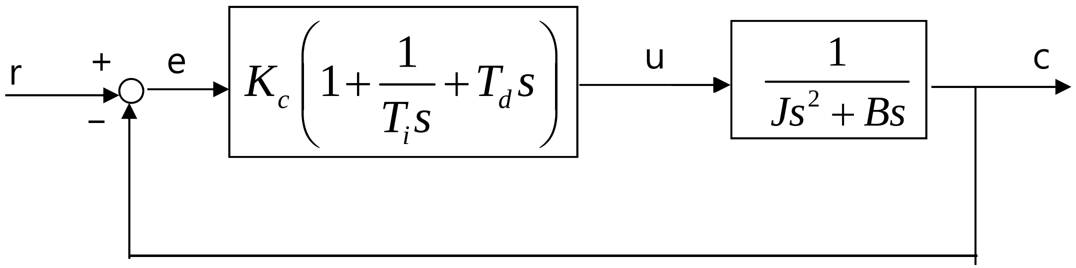
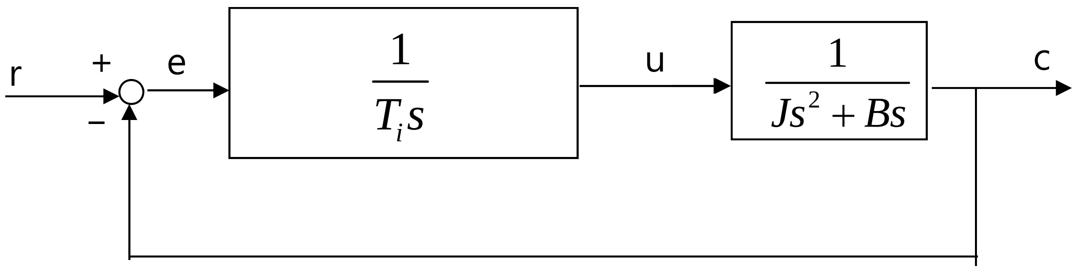
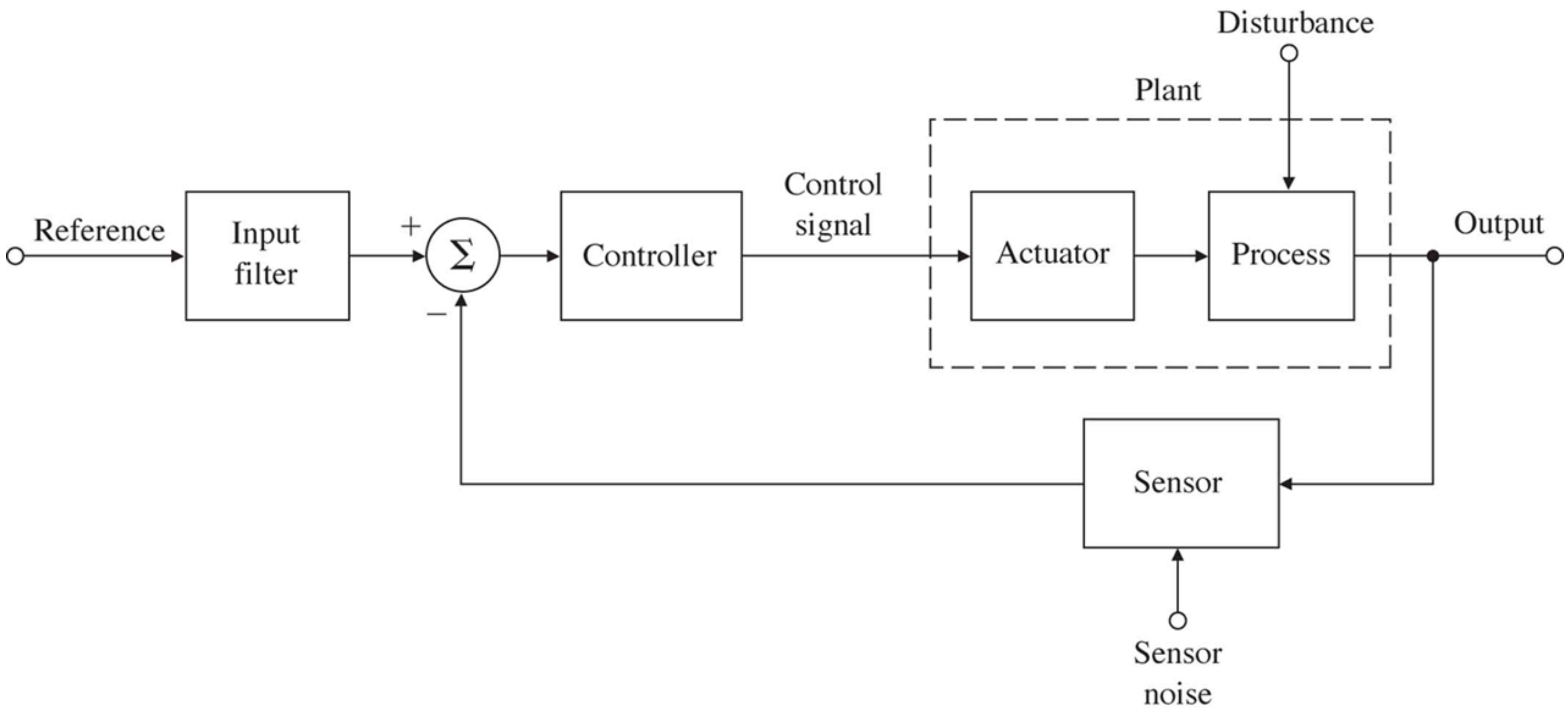


I control



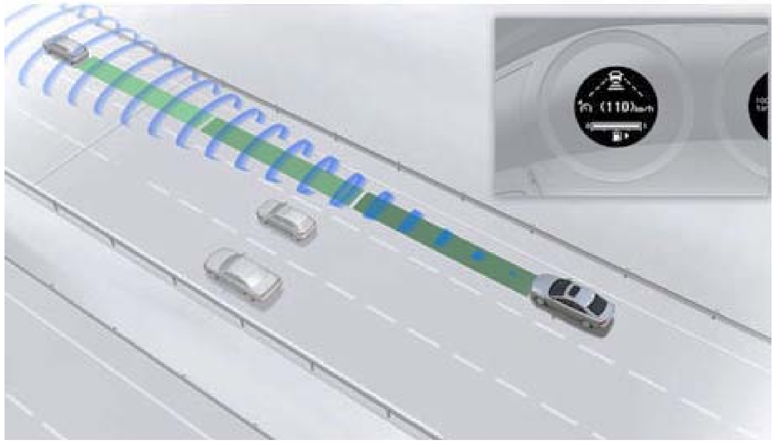
$$\frac{C(s)}{R(s)}=\frac{\frac{1}{T_i s}\frac{1}{Js^2+Bs}}{1+\frac{1}{T_i s}\frac{1}{Js^2+Bs}}=\frac{\frac{1}{T_i}}{Js^3+Bs^2+\frac{1}{T_i}}$$

Component block diagram of an elementary feedback control



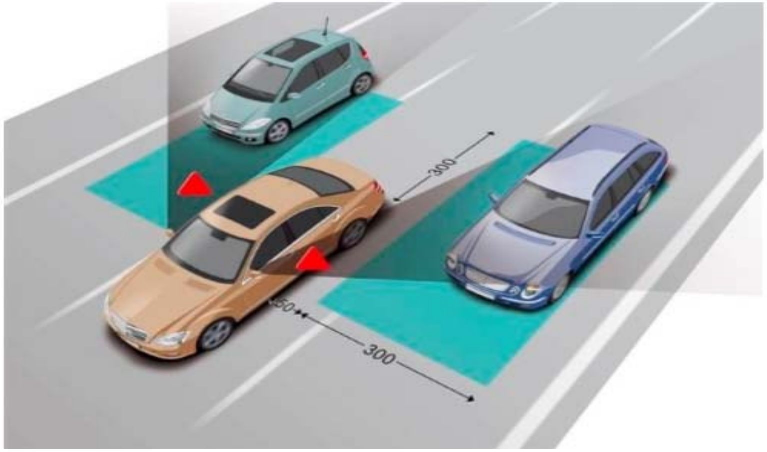
Vehicle control systems

Driver Assistance Systems



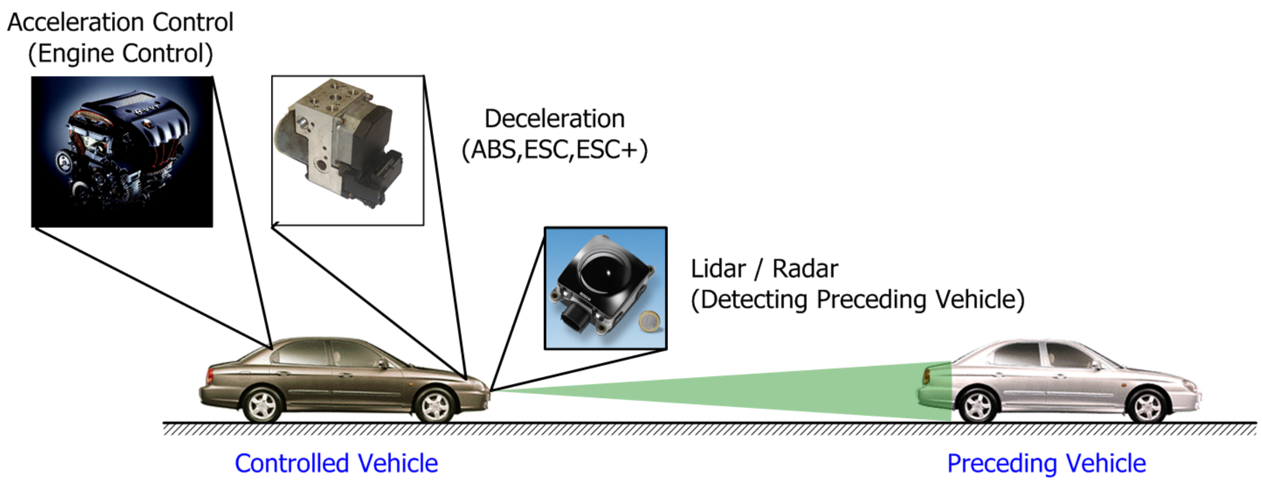
Smart Cruise Control System

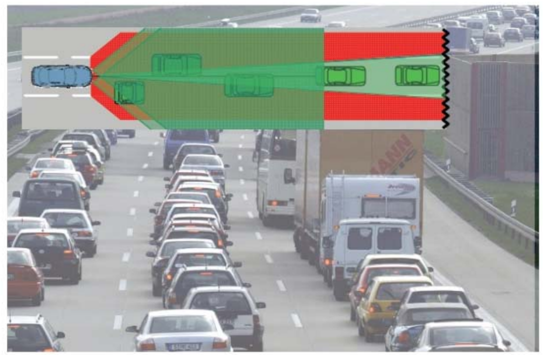
Lane Keeping Assist System



Blind Spot Detection System

Hyundai Motor Company, GENESIS, in 2008





Vehicle Control systems

Cruise Control

Automated Emergency Braking Systems

System Control (next semester)

Controller design

- feedback control systems (closed-loop control systems)
- Root Locus method: pole placement
- Frequency Response method : lead/lag compensators
- analysys and design Using MATLAB
- control system simulation using MATLAB/SIMULINK

- PID Control
- state space method

End of Introduction to Control Systems