8th Lecture

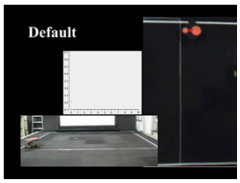
Design examples

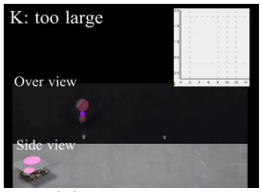
Experiment: Position Control of Mobile Robot

Keyword :

- P control
- Phase compensation
- (Integrator windup)
- 2 Degree of Freedom

Mobile Robot

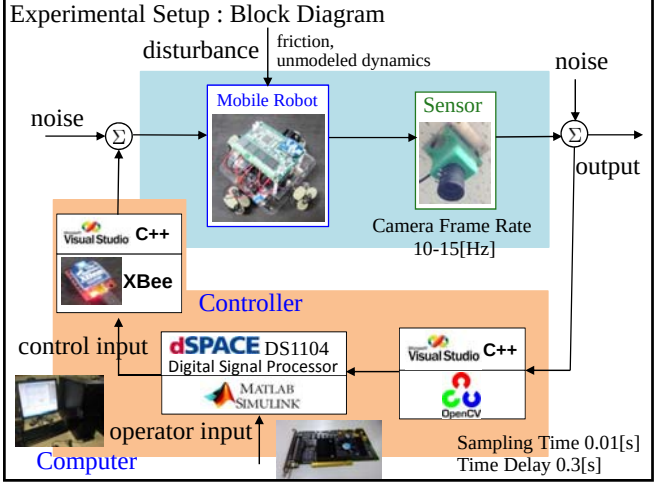




1(x)-directional Velocity Control
(Velocity Tracking)

1(x)-directional Position Control

Experimental Setup : Block Diagram



Experiment: Position Control of Mobile Robot

Mobile Robot

Plant

u_x : Voltage (PWM)
v_x :Velocity

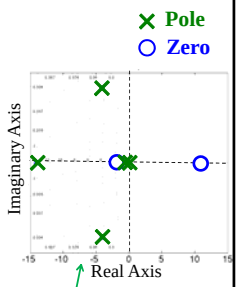
- 1 Input 1 Output (SISO)
- Frequency Limitations

Modeling

- Motion/Circuit Equation
- Identification

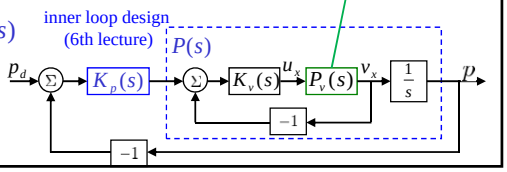
Unstable Zero
(Due to Delay)

$$P(s) = \frac{1.096(s+1.22)(s-11.2)^2}{s(s+14.09)(s+0.6495)(s^2+8.175s+19.47)}$$



Design $K_p(s)$

inner loop design
(6th lecture)



Experiment: Position Control of Mobile Robot

Limitations (4th lecture)

$$P(s) = \frac{1.096(s+1.22)(s-11.2)^2}{s(s+14.09)(s+0.6495)(s^2+8.175+19.47)}$$

All-pass system

$$P_{ap}(s) = \left(\frac{11.2-s}{11.2+s}\right)^2$$

Phase lag of the all-pass system

$$-\arg P_{ap}(j\omega) = -2\{\arg(11.2 - j\omega) - \arg(11.2 + j\omega)\} = 4\tan^{-1}\left(\frac{\omega}{11.2}\right)$$

Gain crossover frequency inequality $n_{gc} = -1, \varphi_m = \frac{\pi}{3}$

$$-\arg P_{ap}(j\omega_{gc}) \le \pi - \varphi_m + n_{gc}\frac{\pi}{2} =: \varphi_l \quad \Rightarrow \quad -\arg P_{ap}(j\omega_{gc}) \le \frac{\pi}{6}$$

Bound on the crossover frequency

$$\Rightarrow \omega_{gc} \le 11.2\tan\frac{\pi}{24} = 1.47[\text{rad/s}]$$

Experiment: Position Control of Mobile Robot

Specifications (2nd lecture)

- Gain Margin $g_m \ge 2$
- Phase Margin $\varphi_m \ge 60$ [deg]
- Fast Response such that $\omega_{gc} \le 1.47$
- Peak $M_s < 2$ $M_T < 1.25$

Gain Margin : $g_m = 1/|L(i\omega_{pc})|$ (9.5) $g_m = 2-5$ (6-14 dB)

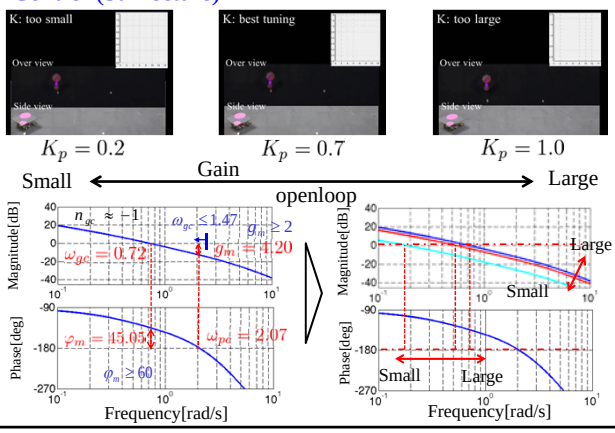
Phase Margin : $\varphi_m = \pi + \arg L(i\omega_{gc})$ (9.6) $\varphi_m = 30^\circ - 60^\circ$

Stability Margin s_m: $s_m = 1/M_s$ $0.5 < s_m < 0.8$

($M_s = 1/s_m$: maximum sensitivity)

Experiment: Position Control of Mobile Robot

P Control (5th lecture)



Experiment: Position Control of Mobile Robot

Phase Lead Compensator (5th lecture)

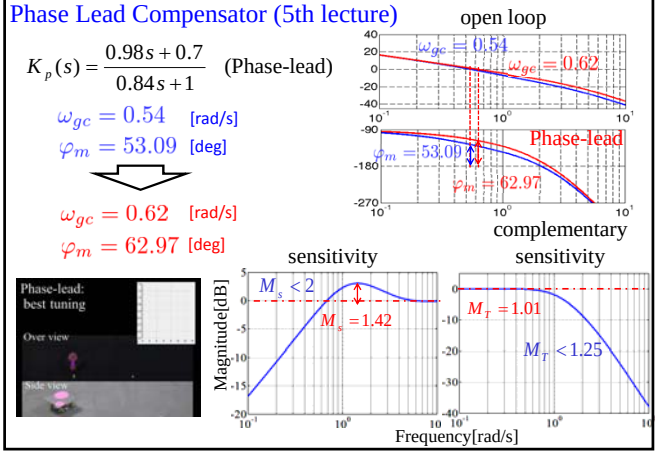
$$K_p(s) = \frac{0.98s + 0.7}{0.84s + 1} \quad \text{(Phase-lead)}$$

$\omega_{gc} = 0.54$ [rad/s]

$\varphi_m = 53.09$ [deg]

$\omega_{gc} = 0.62$ [rad/s]

$\varphi_m = 62.97$ [deg]



Integrator Windup

[Ex. 10.5, 6] Cruise control

Throttle $0 \le u \le 1$

Windup large overshoot

Integrator input

$k_i e \Rightarrow \boxed{k_t e_s} + k_i e$

Steep slope $\theta = 6°$

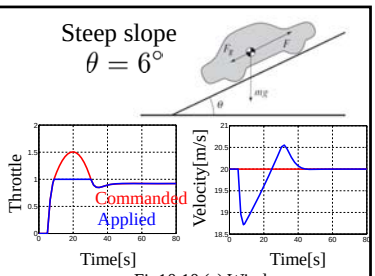
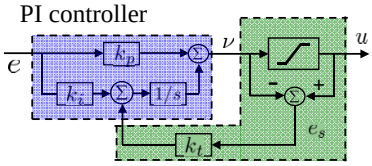


Fig10.10 (a) Windup

PI controller



Anti-windup

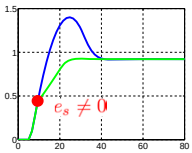


Fig. Integrator output

Experiment: Position Control of Mobile Robot

Integrator Wind up (5th lecture)

$k_p = 0.49$

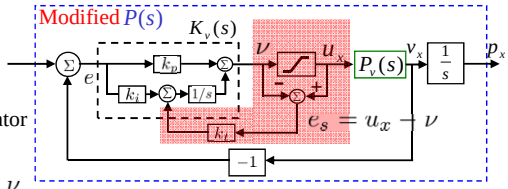
$k_i = 0.60$

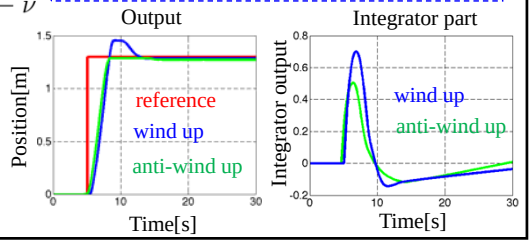
$k_t = k_i$

Input to integrator

$k_t e_s + k_i e$

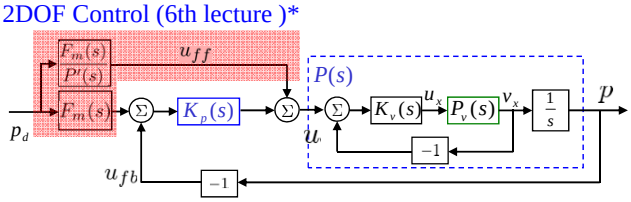
$e_s = u_x - \nu$





Experiment: Position Control of Mobile Robot

2DOF Control (6th lecture)*



Input to $P(s)$

$$u = \frac{F_m(s)}{P(s)} p_d + K_p(s)(F_m(s)p_d - p)$$

$$= u_{ff}(s) + u_{fb}(s)$$

$= 0$ if $p = F_m(s)p_d$

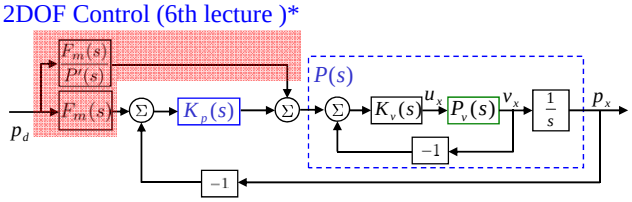
u_{fb} : Feedback term

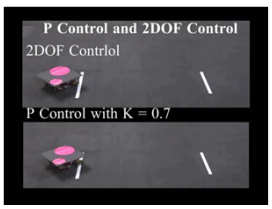
u_{ff} : Feedforward term

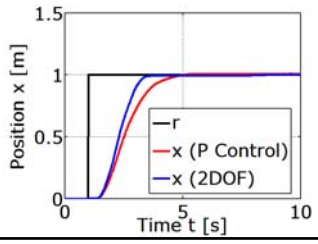
Good response can be achieved by designing $F_m(s)$

Experiment: Position Control of Mobile Robot

2DOF Control (6th lecture)*







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