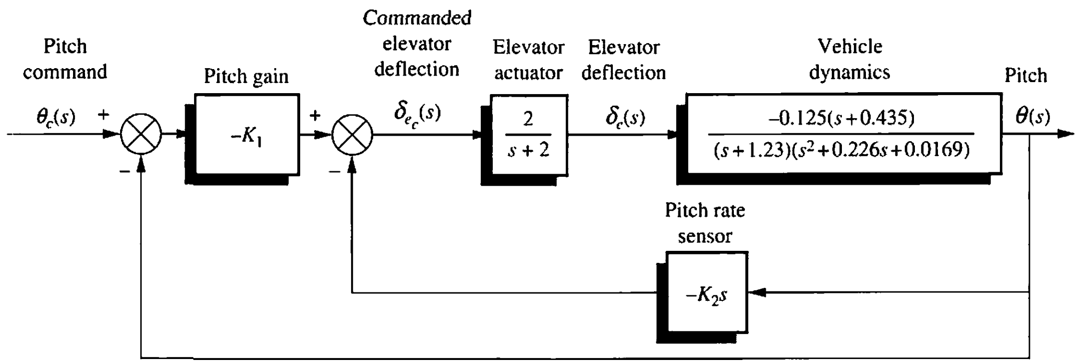
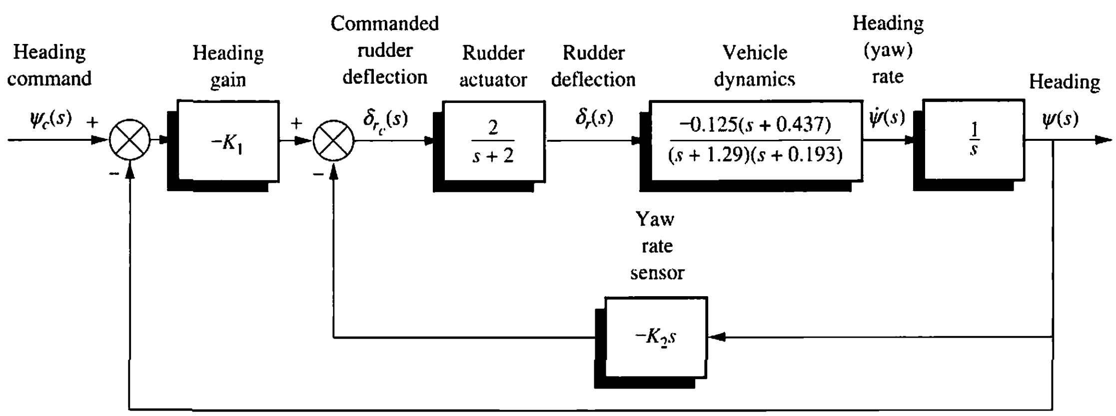
Index

Unmanned Free-Swimming Submersible Vehicle

Pitch Control System



Heading Control System



Key Equations

Modeling

$$\frac{V_o(s)}{V_i(s)} = -\frac{Z_2(s)}{Z_1(s)} \quad (2.97); \qquad \frac{V_o(s)}{V_i(s)} = \frac{Z_1(s)+Z_2(s)}{Z_1(s)} \quad (2.104)$$

$$\frac{\theta_2}{\theta_1} = \frac{r_1}{r_2} = \frac{N_1}{N_2} \quad (2.133); \qquad \frac{T_2}{T_1} = \frac{\theta_1}{\theta_2} = \frac{N_2}{N_1} \quad (2.135)$$

$$\left(\frac{\text{Number of teeth of gear on } \textit{destination} \text{ shaft}}{\text{Number of teeth of gear on } \textit{source} \text{ shaft}}\right)^2 \quad \text{(see after 2.138)}$$

$$\frac{\theta_m(s)}{E_a(s)} = \frac{K_t/(R_aJ_m)}{s\left[s+\frac{1}{J_m}\left(D_m+\frac{K_tK_b}{R_a}\right)\right]} \quad (2.153)$$

$$\frac{K_t}{R_a} = \frac{T_{\text{stall}}}{e_a} \quad (2.162); \quad K_b = \frac{e_a}{\omega_{\text{no-load}}} \quad (2.163)$$

$$T(s) = \frac{Y(s)}{U(s)} = \mathbf{C}(s\mathbf{I}-\mathbf{A})^{-1}\mathbf{B}+\mathbf{D} \quad (3.73)$$

Time Response

$$T_r = \frac{2.2}{a} \quad (4.9); \quad T_s = \frac{4}{a} \quad (4.10)$$

$$G(s) = \frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2} \quad (4.22)$$

$$\%OS = e^{-(\zeta\pi/\sqrt{1-\zeta^2})} \times 100 \quad (4.38)$$

$$\zeta = \frac{-\ln(\%OS/100)}{\sqrt{\pi^2+\ln^2(\%OS/100)}} \quad (4.39)$$

$$T_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} \quad (4.34); \quad T_s = \frac{4}{\zeta\omega_n} \quad (4.42)$$

Steady-State Error

$$e(\infty) = e_{\text{step}}(\infty) = \frac{1}{1+\lim_{s\to 0} G(s)} \quad (7.30); \quad K_p = \lim_{s\to 0} G(s) \quad (7.33)$$

$$e(\infty) = e_{\text{ramp}}(\infty) = \frac{1}{\lim_{s\to 0} sG(s)} \quad (7.31); \quad K_v = \lim_{s\to 0} sG(s) \quad (7.34)$$

$$e(\infty) = e_{\text{parabola}}(\infty) = \frac{1}{\lim_{s\to 0} s^2G(s)} \quad (7.32); \quad K_a = \lim_{s\to 0} s^2G(s) \quad (7.35)$$

Root Locus

$$\angle KG(s)H(s) = -1 = 1\angle(2k+1)180^\circ \quad (8.13)$$

$$\sigma_a = \frac{\sum \text{finite poles} - \sum \text{finite zeros}}{\#\text{ finite poles} - \#\text{ finite zeros}} \quad (8.27)$$

$$\theta_a = \frac{(2k+1)\pi}{\#\text{ finite poles} - \#\text{ finite zeros}} \quad (8.28)$$

$$\theta = \sum \text{finite zero angles} - \sum \text{finite pole angles}$$

$$K = \frac{1}{|G(s)H(s)|} = \frac{1}{M} = \frac{\prod \text{finite pole lengths}}{\prod \text{finite zero lengths}} \quad (8.51)$$

Frequency Response

$$M_p = \frac{1}{2\zeta\sqrt{1-\zeta^2}} \quad (10.52); \quad \omega_p = \omega_n\sqrt{1-2\zeta^2} \quad (10.53)$$

$$\omega_{\text{BW}} = \omega_n\sqrt{(1-2\zeta^2)+\sqrt{4\zeta^4-4\zeta^2+2}} \quad (10.54)$$

$$\Phi_M = \tan^{-1}\frac{2\zeta}{\sqrt{-2\zeta^2+\sqrt{1+4\zeta^4}}} \quad (10.73)$$

$$\phi_{\max} = \tan^{-1}\frac{1-\beta}{2\sqrt{\beta}} = \sin^{-1}\frac{1-\beta}{1+\beta} \quad (11.11)$$

$$\omega_{\max} = \frac{1}{T\sqrt{\beta}} \quad (11.9); \quad |G_c(j\omega_{\max})| = \frac{1}{\sqrt{\beta}} \quad (11.12)$$

State Space

$$\mathbf{C_M} = [\mathbf{B} \quad \mathbf{AB} \quad \mathbf{A}^2\mathbf{B} \quad \cdots \quad \mathbf{A}^{n-1}\mathbf{B}] \quad (12.26)$$

$$\dot{\mathbf{x}} = (\mathbf{A}-\mathbf{BK})\mathbf{x}+\mathbf{B}r; \quad y = \mathbf{Cx} \quad (12.3); \quad \mathbf{O_M} = \begin{bmatrix}\mathbf{C}\\ \mathbf{CA}\\ \vdots\\ \mathbf{CA}^{n-1}\end{bmatrix} \quad (12.79)$$

$$\dot{\mathbf{e}}_\mathbf{x} = (\mathbf{A}-\mathbf{LC})\mathbf{e}_\mathbf{x}; \quad y-\hat{y} = \mathbf{Ce}_\mathbf{x} \quad (12.64)$$

Digital Control

$$e^*(\infty) = \lim_{z\to 1}(1-z^{-1})E(z) \quad (13.66)$$

$$K_p = \lim_{z\to 1} G(z) \quad (13.70); \quad K_v = \frac{1}{T}\lim_{z\to 1}(z-1)G(z) \quad (13.73)$$

$$K_a = \frac{1}{T^2}\lim_{z\to 1}(z-1)^2G(z) \quad (13.75)$$

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On the cover: CHARLI, a 5-foot tall autonomous humanoid robot built by Dr. Dennis Hong and his students at RoMeLa (Robotics and Mechanisms Laboratory) at the College of Engineering of Virginia Tech.

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ISBN 978-0-470-54756-4
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