Spring 2019

數位控制系統
Digital Control Systems

DCS-21
A Design Example

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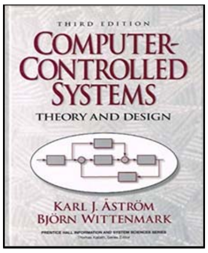
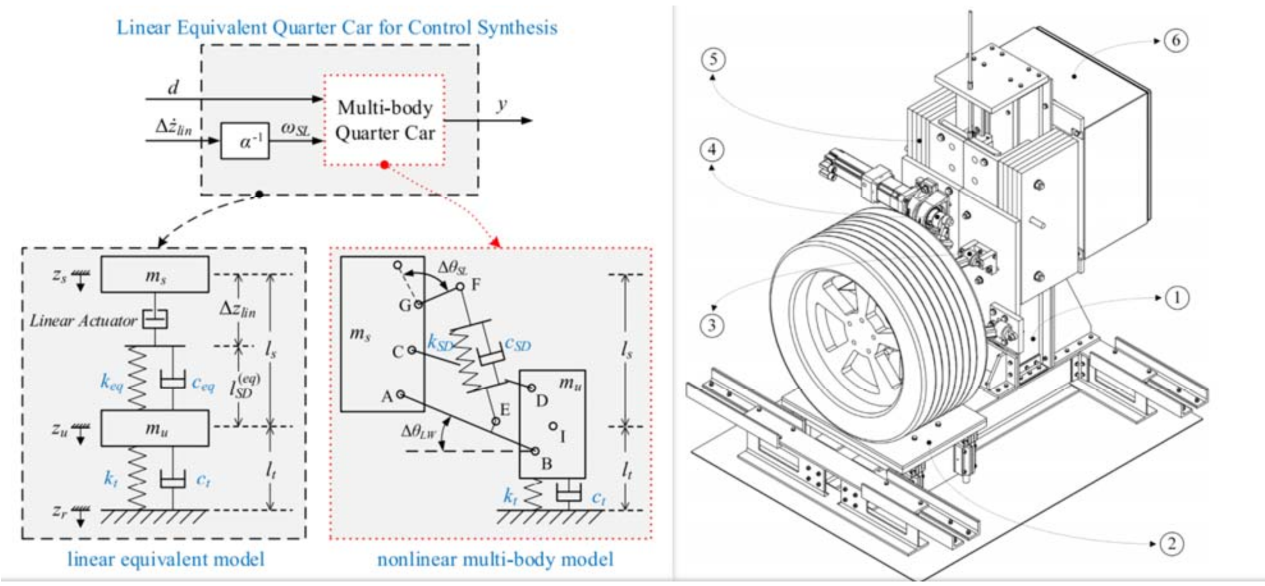
Feb19 – Jun19

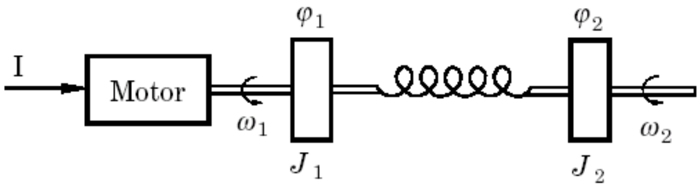


Problem, Model, Analysis, and Design



IEEE CSS
Publications Content Digest
March 2019

- A Flexible Robot Arm:



- CT Input-Output Model:

$$\frac{\text{Output}}{\text{Input}} = \frac{w_2}{I} = \frac{B(s)}{A(s)} = G(s)$$

- CT State-Space Model:

$$\begin{aligned} x_1 &= \phi_1 - \phi_2 \\ x_2 &= w_1 \\ x_3 &= w_2 \end{aligned} \qquad \begin{aligned} \frac{d\mathbf{x}}{dt} &= \mathbf{A}\,\mathbf{x} + \mathbf{B}\,u \\ y &= \mathbf{C}\,\mathbf{x} \end{aligned}$$

- Stability:
- Plant Poles & Zeros: $G(s) = \frac{B(s)}{A(s)} \Rightarrow p_{p1}, p_{p2}, \cdots$
- Plant Eigenvalues: $\frac{d\mathbf{x}}{dt} = \mathbf{A}\,\mathbf{x} + \mathbf{B}\,u$, $y = \mathbf{C}\,\mathbf{x} \Rightarrow \lambda_{p1}, \lambda_{p2}, \cdots$
- Characteristics: $\Rightarrow$ Damping Ratio: ζ_p

  $\Rightarrow$ Natural Frequency: w_p
- Root Locus & Bode Plot
- Impulse Response & Step Response:

- Design Specifications: • $\zeta_d,\ w_d$
- Sampling Time: $\Rightarrow\ w_N > (10 \sim 20) w_d$

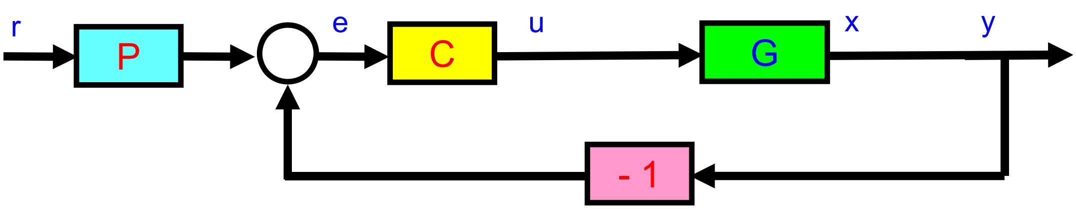
$$\Rightarrow\ h = \frac{2\pi}{w_s} \qquad w_s = 2 w_N$$

- DT Models:

$$G(z) = \frac{B(z)}{A(z)} \qquad \begin{aligned} \mathbf{x}(k+1) &= \mathbf{F}\,\mathbf{x}(k) + \mathbf{H}\,u(k) \\ y(k) &= \mathbf{C}\,\mathbf{x}(k) \end{aligned}$$

- Desired Poles & Zeros: $\Rightarrow\ p_{d1}, p_{d2}, \cdots$
- Desired Eigenvalues: • $\zeta_d,\ w_d$ $\Rightarrow\ \lambda_{d1}, \lambda_{d2}, \cdots$

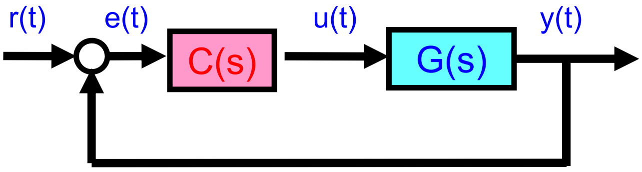
- Block Diagram of a Typical Control System:

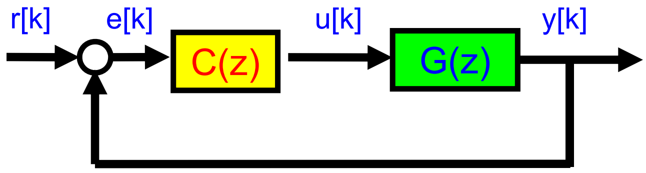


$$G(z) = \frac{B(z)}{A(z)} \qquad p_{p1}, p_{p2}, \cdots \ \Rightarrow\ p_{d1}, p_{d2}, \cdots$$

$$\begin{aligned} \mathbf{x}(k+1) &= \mathbf{F}\,\mathbf{x}(k) + \mathbf{H}\,u(k) \\ y(k) &= \mathbf{C}\,\mathbf{x}(k) \end{aligned} \qquad \lambda_{p1}, \lambda_{p2}, \cdots \ \Rightarrow\ \lambda_{d1}, \lambda_{d2}, \cdots$$

Problem, Model, Analysis, and Design





$$G(s) = \frac{B(s)}{A(s)}$$

$$\frac{d\mathbf{x}}{dt} = \mathbf{A}\,\mathbf{x} + \mathbf{B}\,u$$

$$y = \mathbf{C}\,\mathbf{x}$$

$$h_1 \Rightarrow \quad G_1(z) = \frac{B_1(z)}{A_1(z)}$$

$$\mathbf{x}(k+1) = \mathbf{F}_1\,\mathbf{x}(k) + \mathbf{H}_1\,u(k)$$

$$y(k) = \mathbf{C}_1\,\mathbf{x}(k)$$

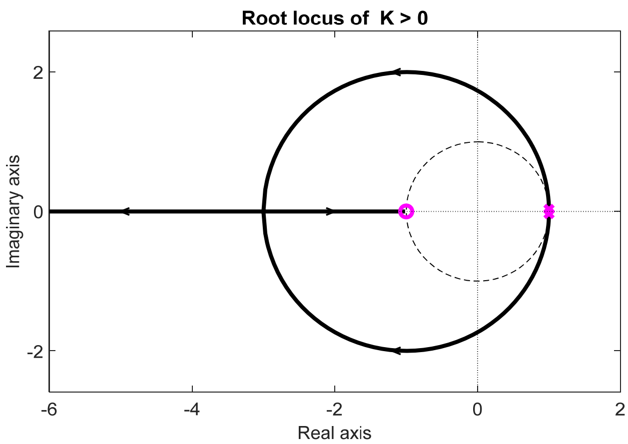
$$h_2 \Rightarrow \quad G_2(z) = \frac{B_2(z)}{A_2(z)}$$

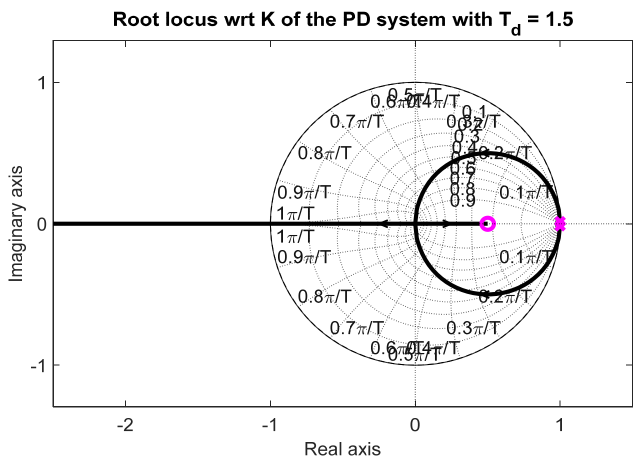
$$\mathbf{x}(k+1) = \mathbf{F}_2\,\mathbf{x}(k) + \mathbf{H}_2\,u(k)$$

$$y(k) = \mathbf{C}_2\,\mathbf{x}(k)$$

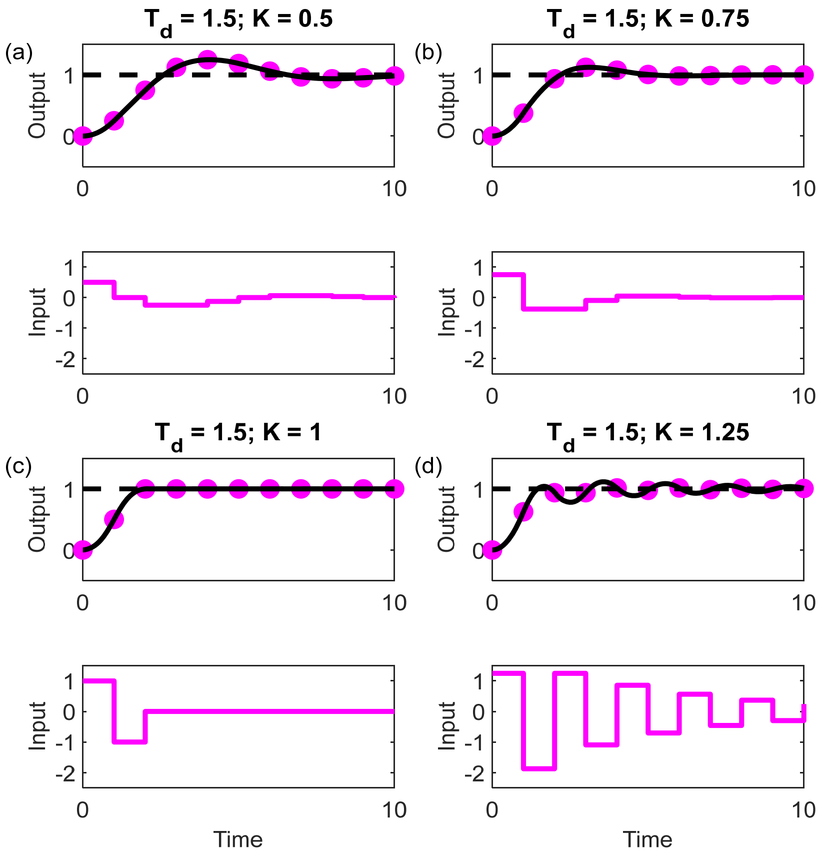
Simulation Study

- Root Locus:

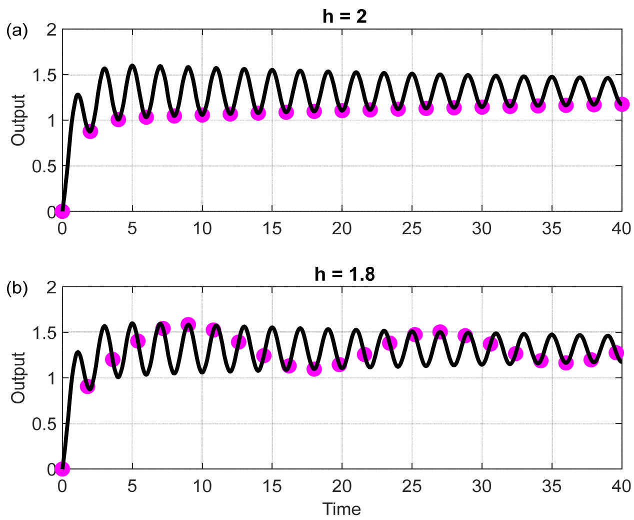


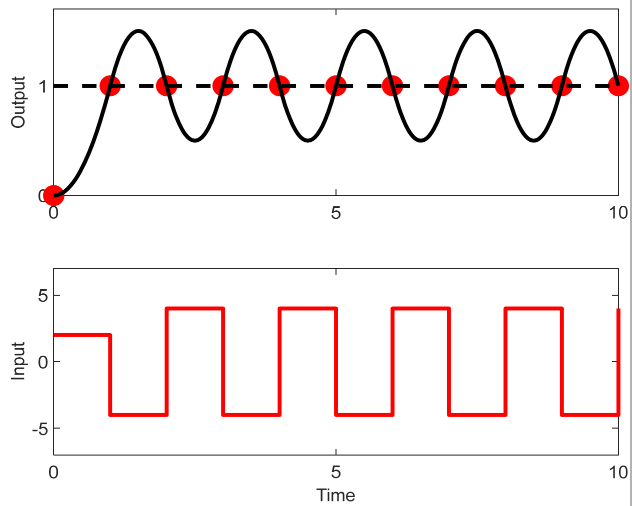


▪ Step Reponses of Different Gains:



▪ Hidden Oscillation of Different Sampling Periods:





The Research Procedure in Control Science

Physical Process → Math Model → System Analysis → Control Design

Physical Process

- Plant
- Sensor
- Actuator
- Computer
- Communication
- Noise
- Disturbance

Math Model

- Differential eqn
- Laplace transform
- Transfer function
- State space form

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- Difference eqn
- z transform
- Transfer function
- State space form

System Analysis

- Root locus
- Bode diagram
- Nyquist plot

- Stability
- Robustness
- Sensitivity
- Controllability
- Observability

Control Design

- Estimator
- Identification
- Regulation
- Tracking
- PID
- Pole placement
- Optimal Control LQR/LQG
- Adaptive control
- Robust control
- Decentralized (or Multi-person) Control