SPRING 2010

即時控制系統設計
Design of Real-Time Control Systems

Lecture 21
Fundamentals of Digital Control

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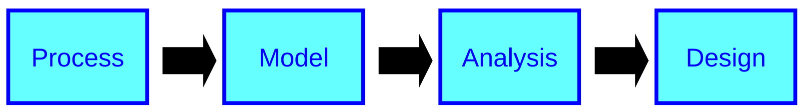
Feb10 – Jun10

- Study in Digital Control Systems
  - Introduction
  - Mathematical model of digital control systems
  - Dynamic analysis of digital control systems
  - Controller design of digital control systems
- Digitalization
  - Control system block diagram
  - Sampling rate
  - Time delay

- The Research Procedure in Control Science



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

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

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

- Root locus
- Bode diagram
- Nyquist plot

- Stability
- Robustness
- Sensitivity
- Controllability
- Observability

- Estimator
- Identification
- Regulation
- Tracking
- PID
- Pole placement

- Optimal Control LQR/LQG
- Adaptive control
- Robust control

- Study in Digital Control Systems
  - Introduction:
    - Systems:
      - > continuous-time systems
      - > discrete-time systems
      - > sampled-data systems
      - > digital systems
    - Controls:
      - > analog/continuous control
      - > digital/discrete control
      - > classical control
      - > modern control
    - Design Issues:
      - > hardware
      - > software

Study in Digital Control Systems

- Characteristics of DT Control Systems
  - open-loop systems
  - A/D converters
  - D/A converters
  - Resolver/synchror-to-digital converters
  - closed-loop systems

  - computer
  - microcontroller
  - DSP
  - microprocessor

Study in Digital Control Systems

- Mathematical Model of Digital Control Systems
  - Discrete-time systems
  - Linear difference equations
    - Derivative approximation:
      - With a forward difference (Euler's method)
      - With a backward difference
      - With a trapezoidal method (Tustin's approximation)
  - Unit pulse function, unit step function, etc.,
    - discrete convolution
    - the z-transform
      - Definition
      - Properties
      - Convergence

Study in Digital Control Systems

- Mathematical Model of Digital Control Systems
  - From analog to digital
    - sampling/sampling times
    - time & frequency characteristics
  - DT transfer functions
    - via Numerical Integration
      - Forward rule (Euler's method)
      - Backward rule
      - Trapezoidal rule (Tustin's method, bilinear transformation)
      - Bilinear transformation with pre-warping
    - via Zero-Pole Matching
    - via Hold equivalents
  - DT frequency response
  - Relationship between s and z domains

Study in Digital Control Systems

- Dynamic Analysis of Digital Control Systems
  - By Transform methods (by transfer function)
    - poles, zeros
    - stability
    - transient response
    - steady-state response
    - impulse/step response
    - root locus
    - Bode plot
  - By State-Variable methods (by state-space model)
    - CT -> DT
    - linear
    - nonlinear
    - stability analysis
    - sensitivity analysis
    - controllability
    - observability

Study in Digital Control Systems

- Controller Design of Digital Control Systems
  - Design Process
    - Emulation:
      - CT plant -> CT controller -> DT controller
    - Discrete Design:
      - CT plant -> DT plant -> DT controller
    - Direct Design: (B.D.O. Anderson, 1992 Bode Prize Lecture)
      - CT plant -> DT controller

Study in Digital Control Systems

- Controller Design of Digital Control Systems
  - Transfer Function Design Methods
    - Dynamic parameters
      - peak time
      - overshoot
      - settle time
      - rise time
    - Steady-state parameters
      - steady-state error
    - Design tools
      - root-locus in z-domain
        design specifications
      - frequency response methods
        design specifications
        gain & phase margins
        tracking error, stability robustness in terms of sensitivity function
        Bode plots, Nyquist stability criterion
        compensator design

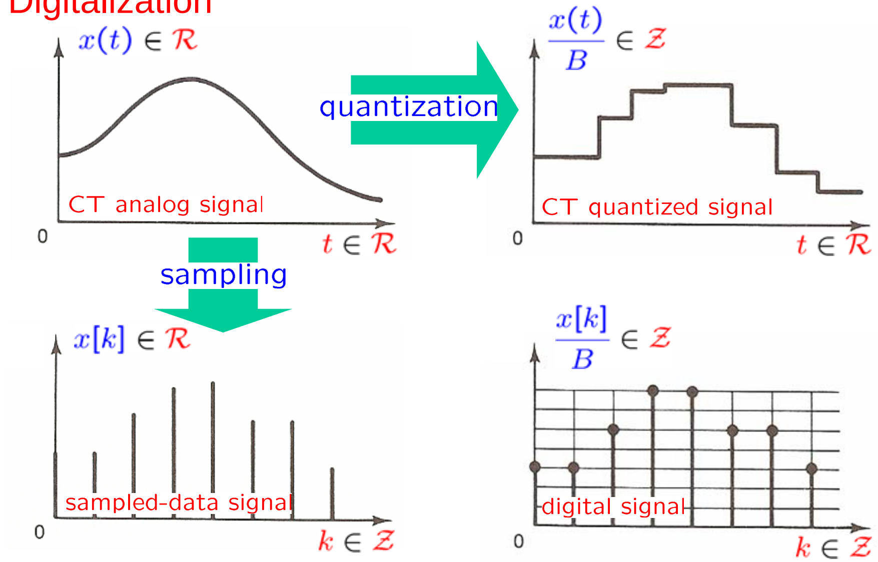
Study in Digital Control Systems

- Controller Design of Digital Control Systems
  - Transfer Function Design Methods
    - Design techniques:
      - Tustin's Method or bilinear approximation
      - Matched Pole-Zero method (MPZ)
      - Modified Matched Pole-Zero method (MMPZ)
    - Compensator/controller
      - pole placement & model matching
      - phase-lead & phase lag compensators
      - PID controller
      - deadbeat controller

Study in Digital Control Systems

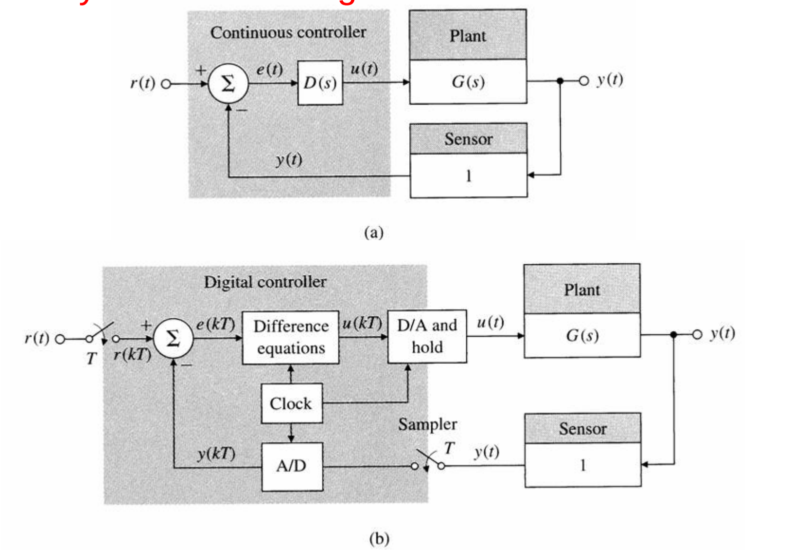
- Controller Design of Digital Control Systems
  - State-Space Design Methods
    - Analysis
    - Design
      - state feedback (controllability)
      - state estimation (observability)
      - regulator: controller + estimator
      - linear quadratic optimal control (LQR, LQG)
      - nonlinear control

- Digitalization



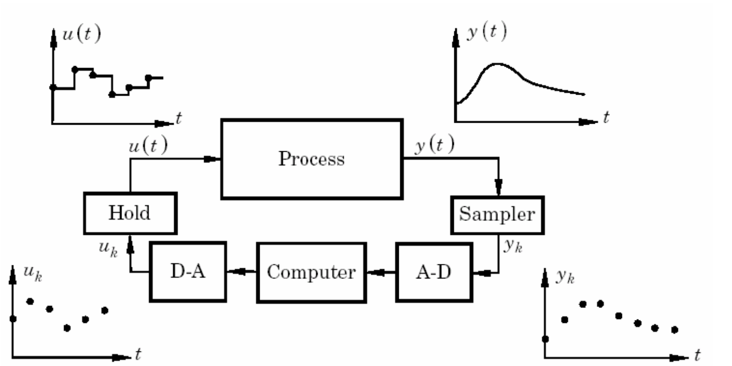
Ogata 1995

- Control System Block Diagram



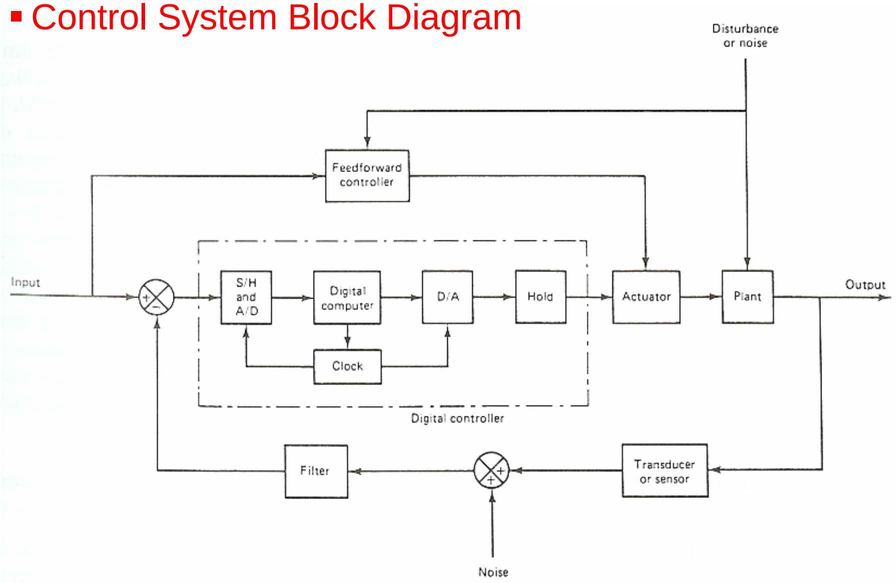
Franklin, Powell & Emami-Naeini 2002

- Control System Block Diagram



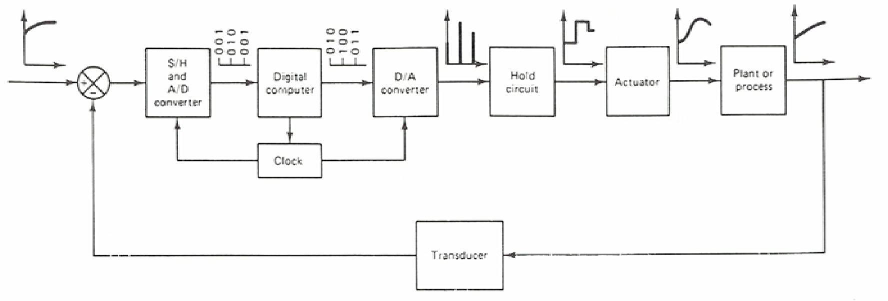
Astrom & Wittenmark 1997

- Control System Block Diagram



Ogata 1995

Control System Block Diagram



Ogata 1995

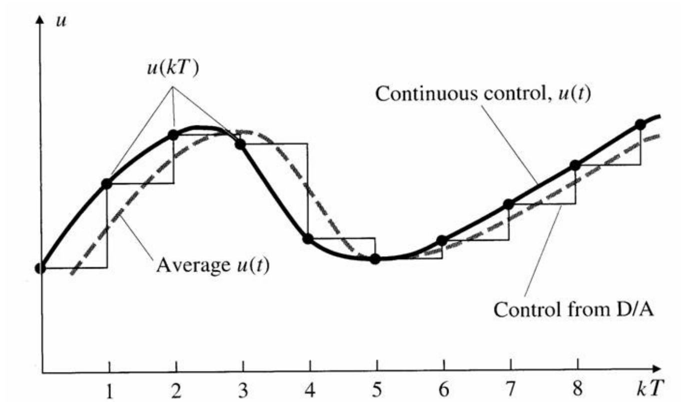
Sample Rate:

- The sample rate required depends on the closed-loop bandwidth of the system
- Generally, sample rates should be about 20 times the bandwidth or faster in order to assure that the digital controller will match the performance of the CT controller

Franklin, Powell & Emami-Naeini 2002

Time Delay:

- The delay associated with the hold
- On average, continuous signals are delayed by T/2



Franklin, Powell & Emami-Naeini 2002