SPRING 2010

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

## Lecture 02
## Introduction


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NTU-EE


Feb10 – Jun10

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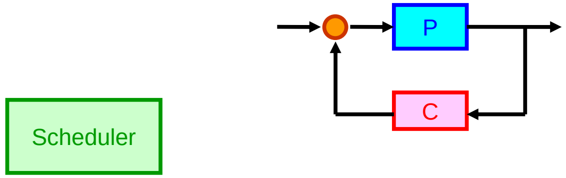
## Basic Concept of Real-Time Control Systems

# 即時 控制系統 設計




- 即時化 控制系統
- 控制 即時系統
- 系統設計與考量

02/16/09

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## Course Topics

- Computer Control Systems (Single Centralized Control)
  - Real-Time Operation Systems
  - Analog to Digital
  - Digital to Analog
- Digital Control Systems
  - From Analog to Digital World
  - Design Considerations
  - Z-transform
  - Controller Design
- Networked Control Systems (Multiple Distributed Control)
  - Real-Time Communication Protocols
  - Networked Controllers & Managers
  - Networked Sensors
  - Networked Actuators

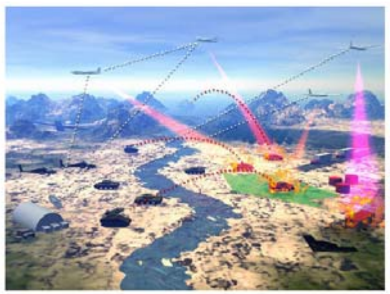

**Figure 3.2.** *Battle space management scenario illustrating distributed command and control between heterogeneous air and ground assets. Figure courtesy of DARPA.*

Murray 2002

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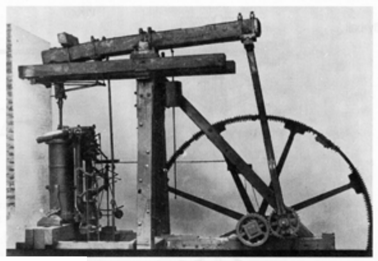
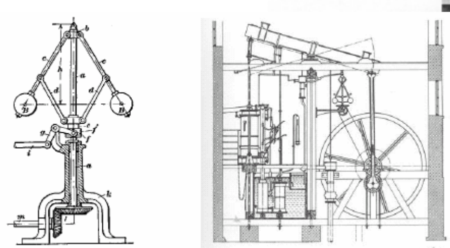
## Introduction: Analog Control Systems

Figure 1.9
A steam engine from the shop of James Watt. (*British Crown Copyright, Science Museum, London*)



Franklin, Powell, Emami-Naeini 2002



(a) (b)

**Figure 1.1.** *The centrifugal governor (a), developed in the 1780s, was an enabler of the successful Watt steam engine (b), which fueled the industrial revolution. Figures courtesy of Cambridge University.*

Murray 2002

Murray 2002

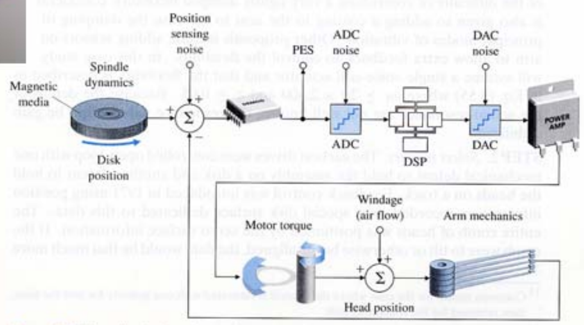
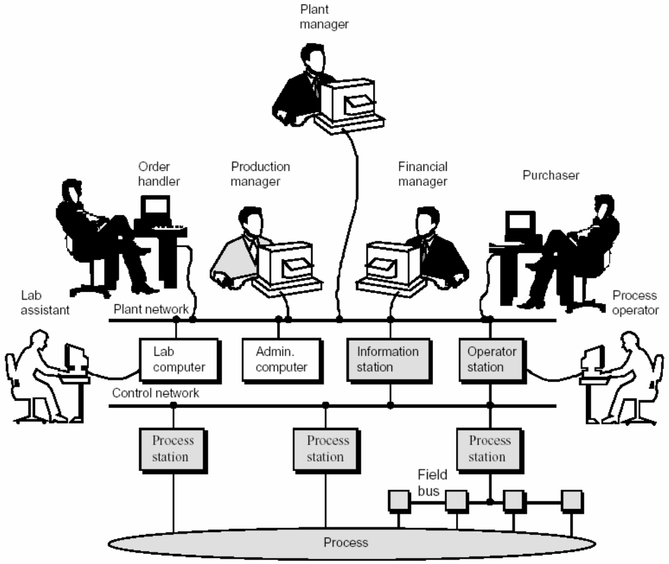



Figure 9.73 Generalized view of track-following model

Franklin, Powell, Emami-Naeini 2002






Astrom & Wittenmark 1997



- Digital Control
  - Sensors, actuators, controller, A/D, D/A
  - Sampling rate

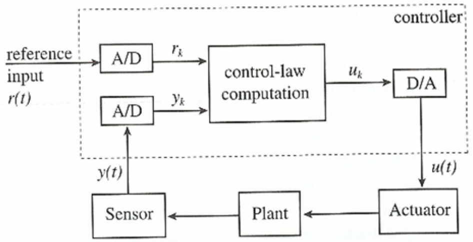



FIGURE 1–1 A digital controller.

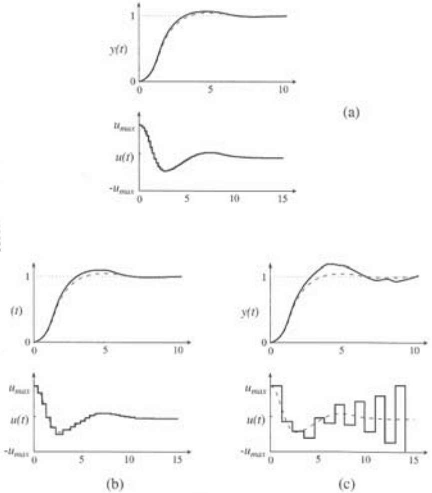



FIGURE 1–2 Effect of sampling period.





- Air Traffic Control
  – Guidance and control
  – Real-time control and command

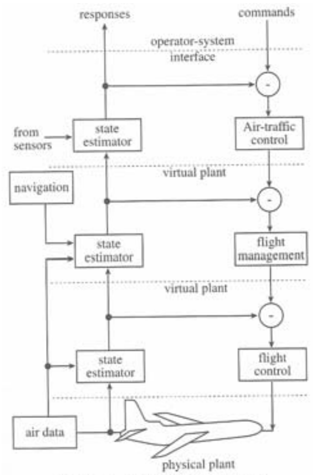



FIGURE 1–4 Air traffic/flight control hierarchy.

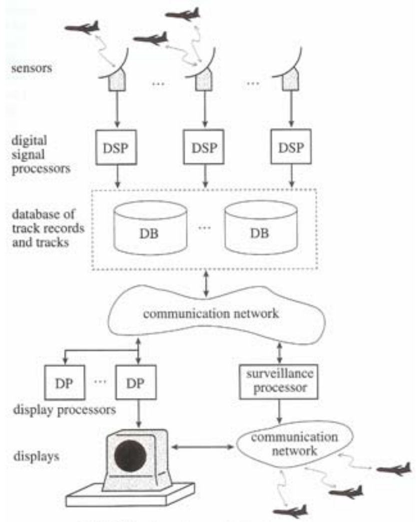



FIGURE 1–5 An architecture of air traffic control system.

- Radar Signal Processing
  - Tracking: gating and data association

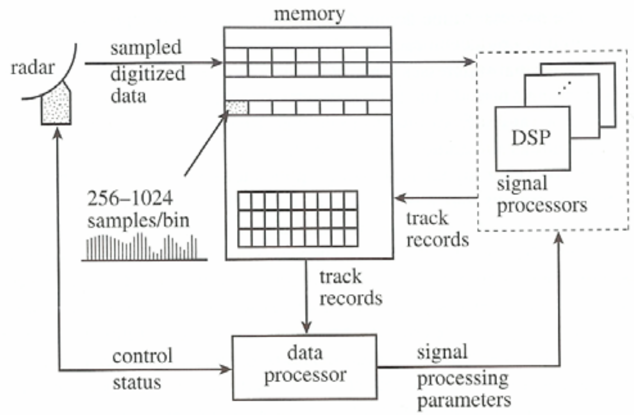



FIGURE 1–6 Radar signal processing and tracking system.





- Real-Time Databases

TABLE 1–1 Requirements of typical real-time databases

| Applications | Size | Ave. Resp. Time | Max Resp. Time | Abs. Cons. | Rel. Cons. | Permanence |
|---|---|---|---|---|---|---|
| Air traffic control | 20,000 | 0.50 ms | 5.00 ms | 3.00 sec. | 6.00 sec. | 12 hours |
| Aircraft mission | 3,000 | 0.05 ms | 1.00 ms | 0.05 sec. | 0.20 sec. | 4 hours |
| Spacecraft control | 5,000 | 0.05 ms | 1.00 ms | 0.20 sec. | 1.00 sec. | 25 years |
| Process control | | 0.80 ms | 5.00 sec | 1.00 sec. | 2.00 sec | 24 hours |

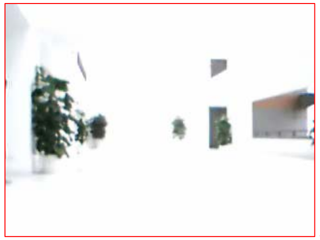
- Multimedia Applications: MPEG
  - Compression/Decompression
  - Motion estimation
  - Discrete Cosine Transform
  - Encoding



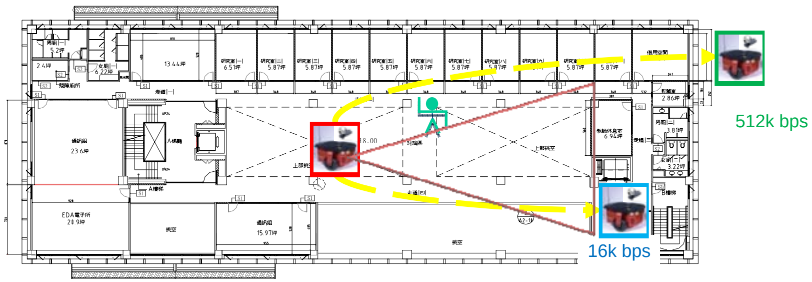


- Real-Time Visual Surveillance System
  - Image acquisition by mobile cameras
  - Motion detection and object tracking
  - Data compression and transmission

  - Communication bandwidth
  - Computational power
  - Motion variable



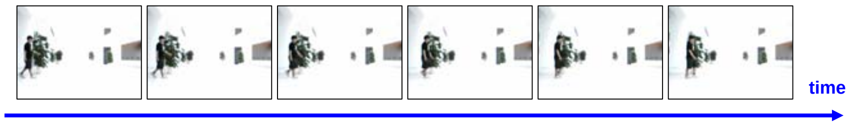
15 fps



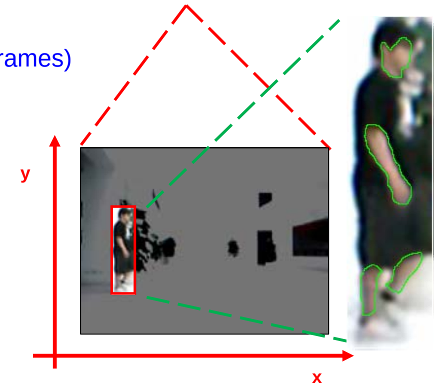





- Real-Time Visual Surveillance System
  - Image sequence from mobile camera




1. Temporal (between consequential frames)
   a) High fidelity
2. Spatial (in one frame)
   a) Background is not a region of interest
   b) High fidelity of color in one region



- Real-Time Visual Surveillance System
  - Decision on
    - Image Processing (computational power)
      - > Image Acquisition
      - > Temporal Sampling
      - > Spatial Sampling
      - > Display / Animation
    - Communication (network bandwidth)
      - > Data Coding / Image Compression
      - > Transmission Rate
      - > Routing Path
    - Control (dynamic response)
      - > Motion Detection
      - > Object Tracking
      - > Camera Control





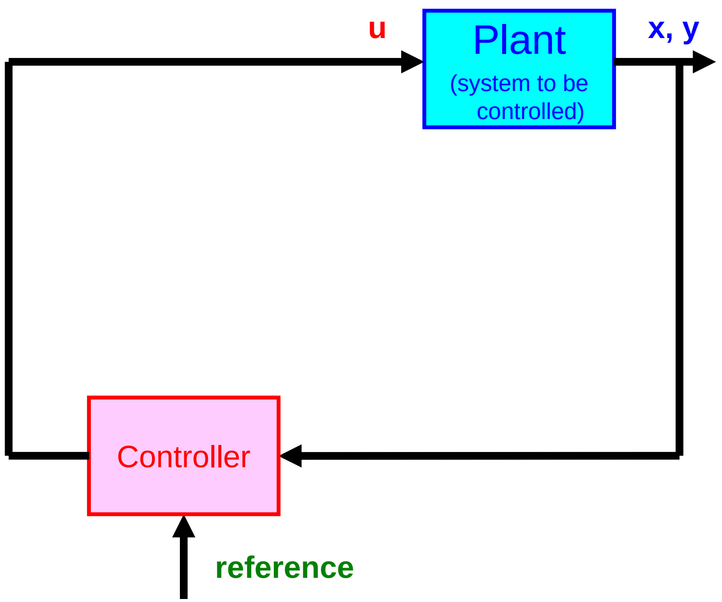
- Real-Time Control is
  - Very-Fast Control?

    or

  - Time-Critical Control?

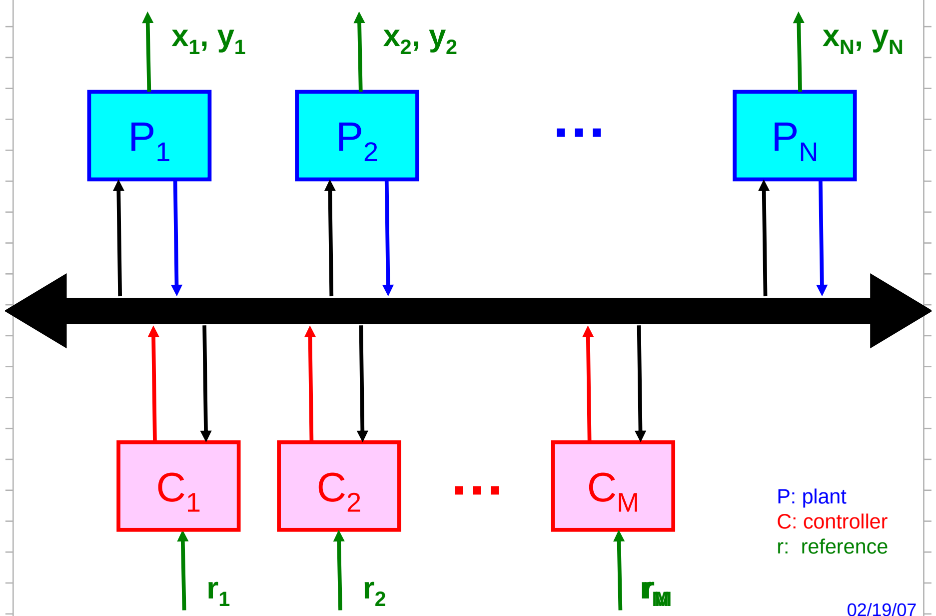




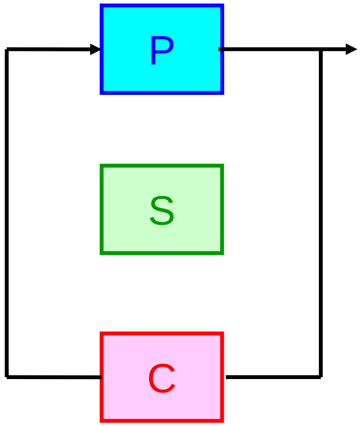




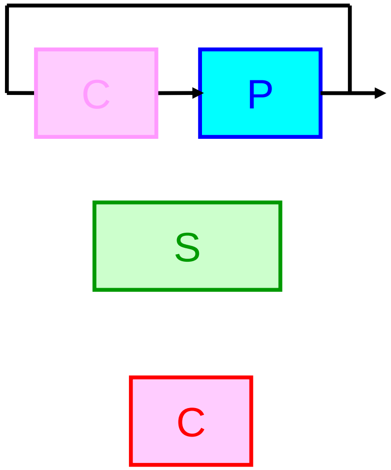


- Control over Real-Time System

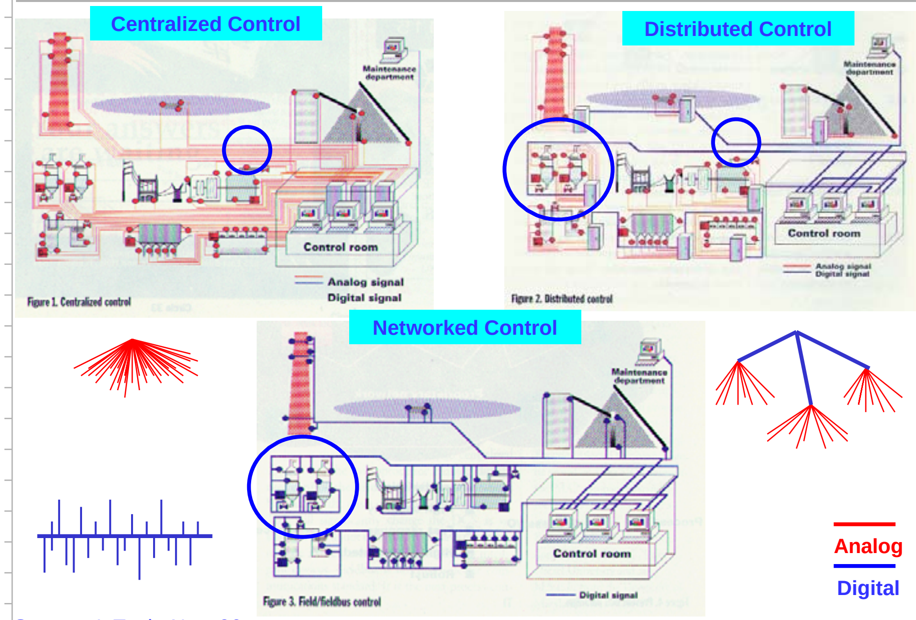



- Control the Real-Time System




P: plant
C: controller
S: scheduler



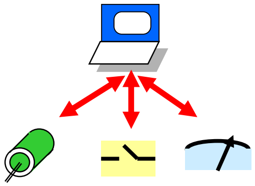



Source: InTech, Nov. 96

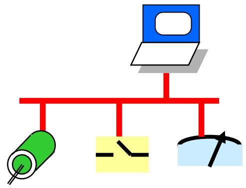




- Real-Time Control Systems:
  - Computing, Communication, and Control



Centralized Control System



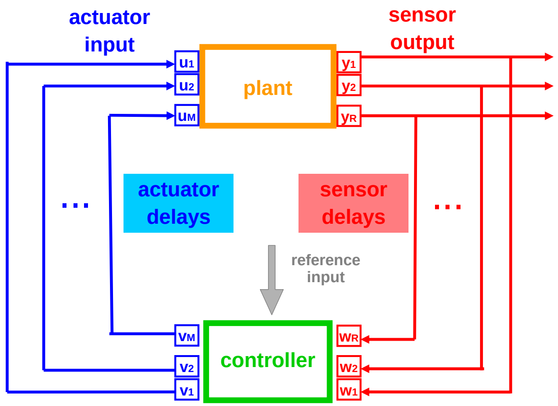
Distributed Control System

- Controlled by one computer processor
  - Centralized control systems
  - Real-time operating systems
- Controlled by one communication medium
  - Distributed control systems
  - Real-Time Communications

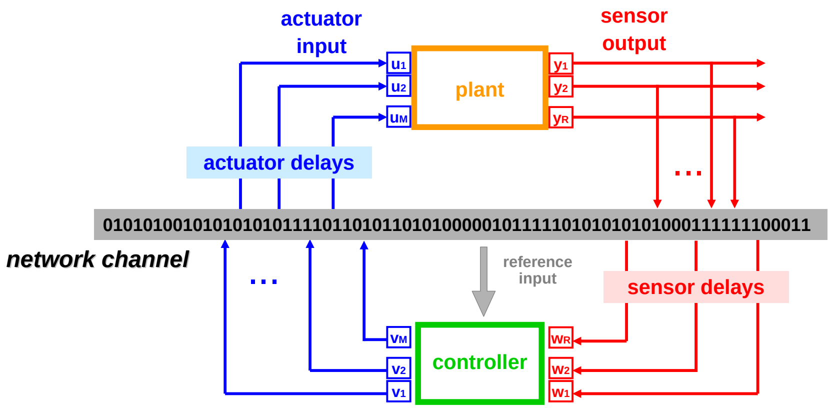




- Real-Time Control Systems:
  - Computing, Communication, and Control

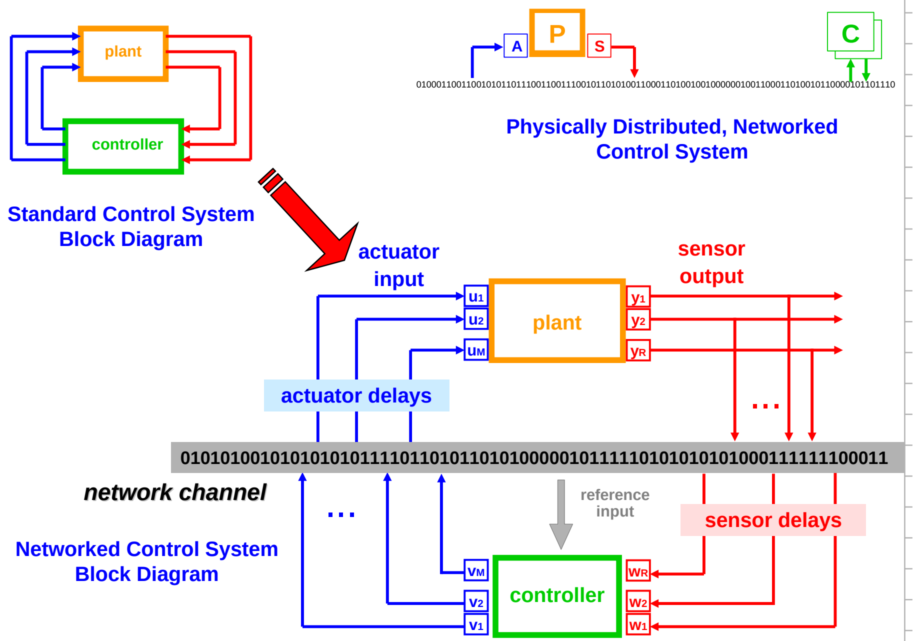


- Real-Time Control Systems:
  - Computing, Communication, and Control



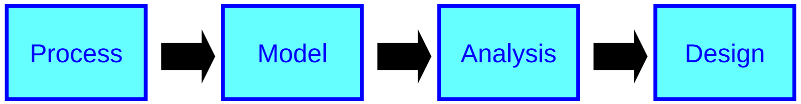





## The Design Philosophy of Control Science

- The Research Procedure in Control Science




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

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

↓

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

- Root locus
- Bode diagram
- Nyquist plot

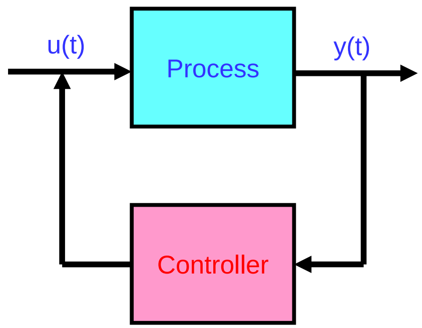
- Stability
- Robustness
- Sensitivity
- Controllability
- Observability

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

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

## Introduction: Feedback Control Systems

- Feedback Control Systems

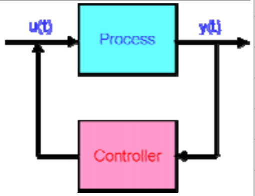


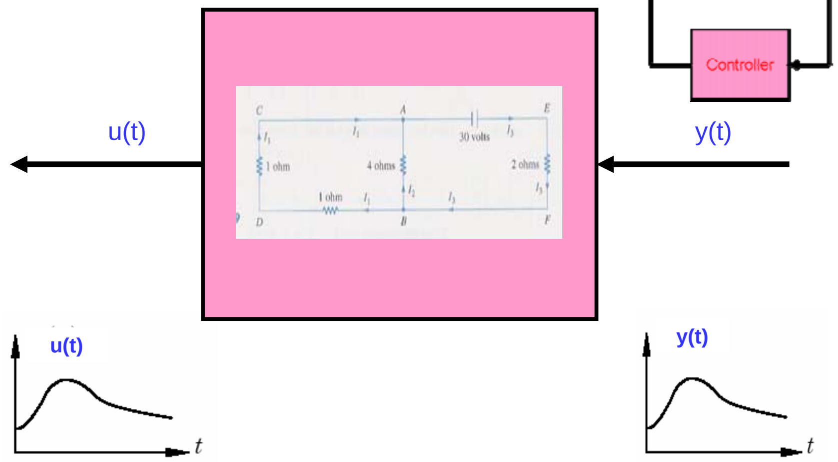

- Analog Controller:
- Digital Controller:

## Introduction: Analog Controller



- Analog Controller:

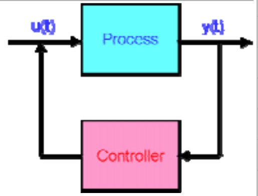


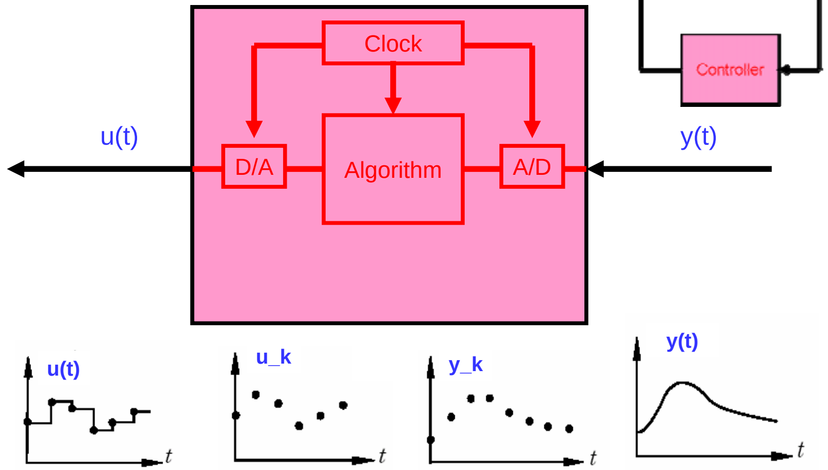




## Introduction: Digital Controller



- Digital Controller:

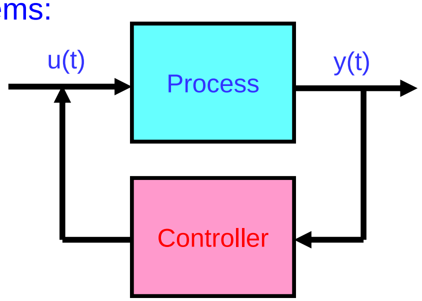


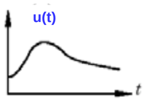




## Introduction: Control Systems

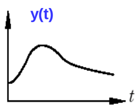


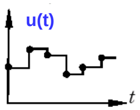
- Control Systems:



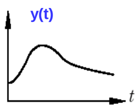




- Analog Controller:



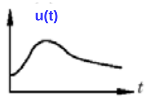




- Digital Controller:

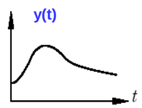


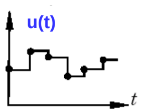

## Introduction: Analog and Digital Controllers



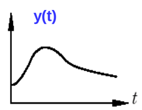



- Analog Controller:
- Continuous-time systems




- Digital Controller:

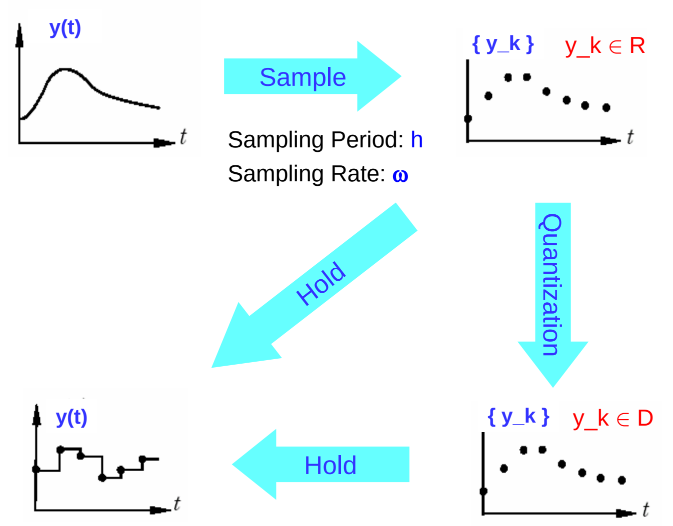



- Discrete-time systems
- Sampled-data systems
- Computer-controlled systems
- Digital control systems

- Digital Signals
  - D: Resolution set of digital signals
  - E.X. Use 3 bits to represent a signal between –7V to 7V
  - then, 2^3 = 8
    - that is, there are 8 levels and 7 intervals
  - so, [ 7 – (-7) ] / 7 = 2
  - hence,
    - 000 = 0 ⇒ -7V
    - 001 = 1 ⇒ -5V
    - 010 = 2 ⇒ -3V,
    - …
    - 111 = 7 ⇒ 7V
  - So, D = { -7, -5, …, 7 }
    - which can be mapped into Z+ = {0, 1, 2, …,N}

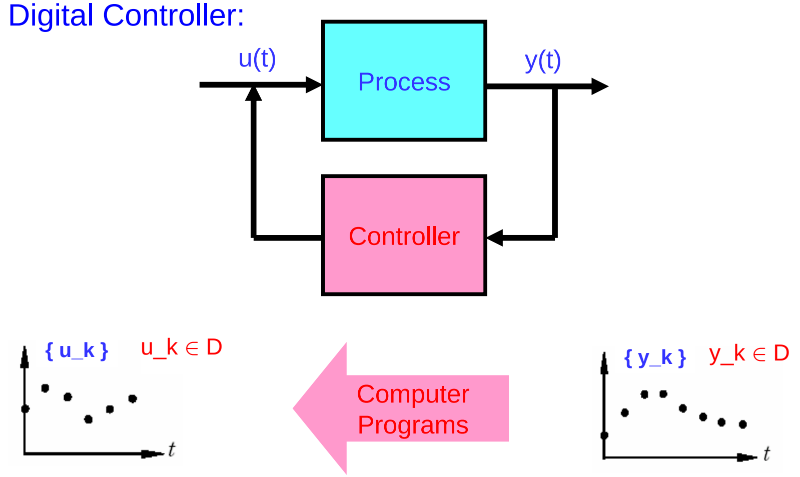


- Discrete-Time Signals






- Digital Controller:

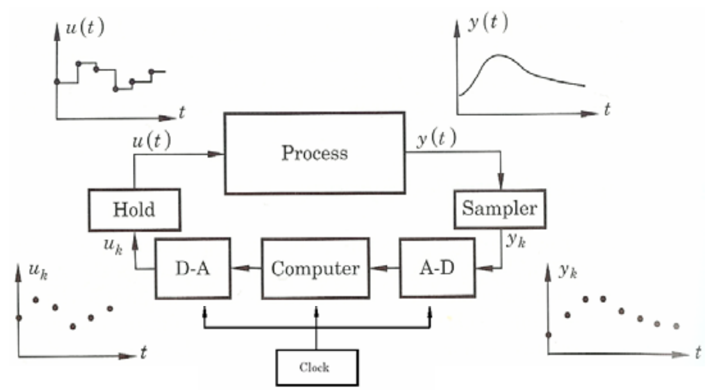



controller algorithm

$$\{u_k\} = g(\{y_k\})$$

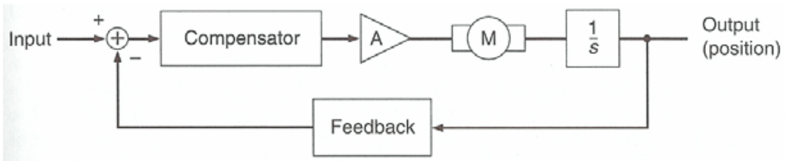


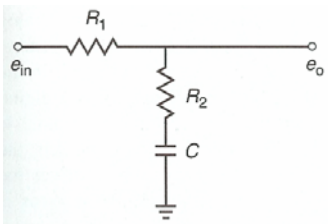
- Key Components of Digital Control Systems



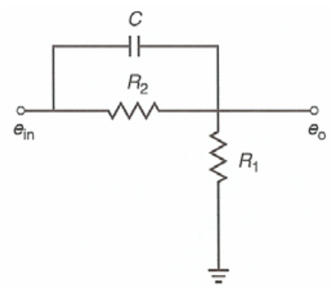

Astrom & Wittenmark 1997

## ▪ Analog Servo-Control System




Lag compensator

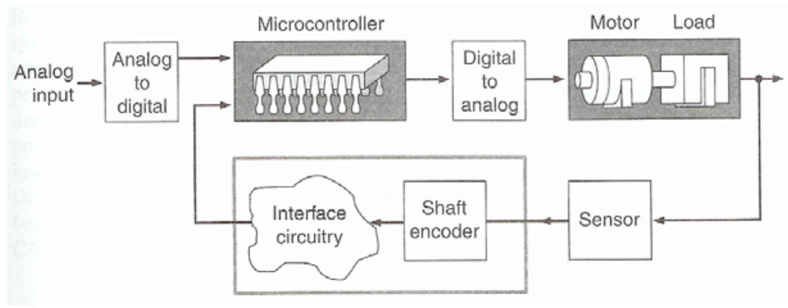



Lead compensator

Nekoogar & Moriarty 1999



## ▪ Digital Motor Position Control System

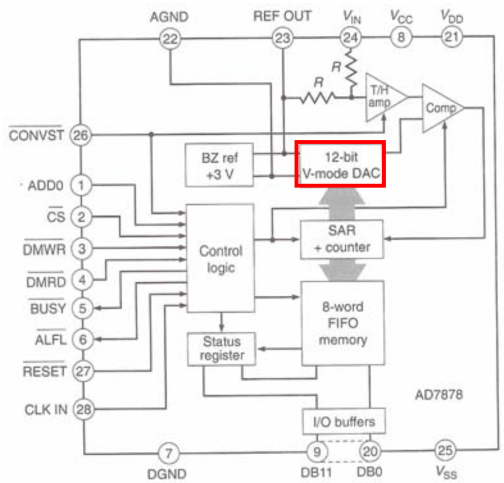



Nekoogar & Moriarty 1999



## ▪ Analog to Digital Converter (Analog Devices, Inc.)

analog input




digital signal output

digital output

Nekoogar & Moriarty 1999



## ▪ Analog to Digital Converter

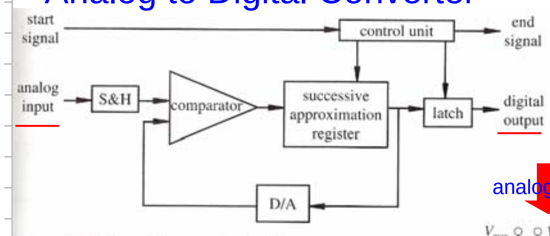


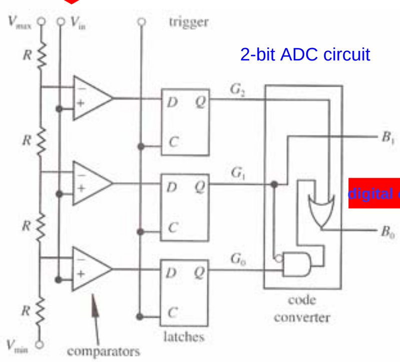

**Figure 8.8** Successive approximation A/D converter.

**Table 8.1** 2-bit flash converter output

| State | Code ($G_2G_1G_0$) | Binary ($B_1B_0$) | Voltage range |
|---|---|---|---|
| 0 | 000 | 00 | 0–1 |
| 1 | 001 | 01 | 1–2 |
| 2 | 011 | 10 | 2–3 |
| 3 | 111 | 11 | 3–4 |

analog input

2-bit ADC circuit

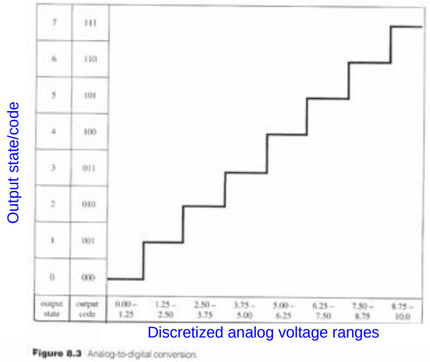



digital output

**Figure 8.10** A/D flash converter.

Alciatore & Histand 2003

- Analog to Digital Converter



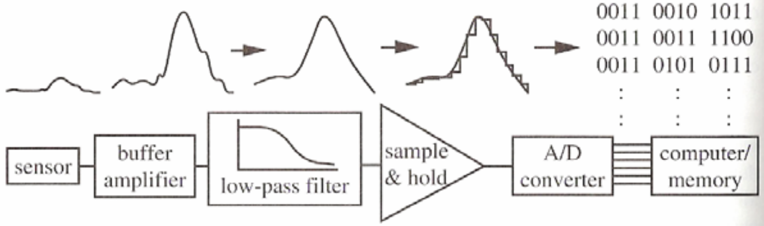
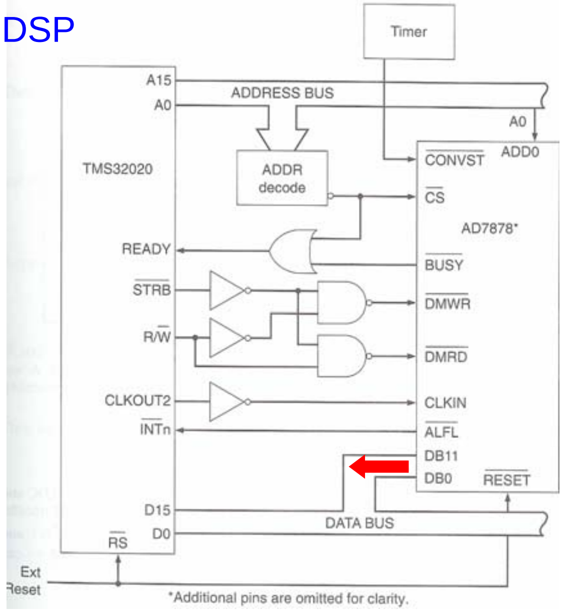




**Figure 8.4** Components used in A/D conversion.

Alciatore & Histand 2003



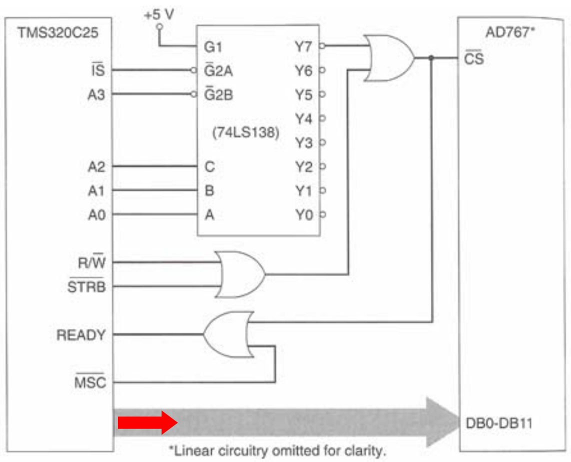
- ADC to DSP




Nekoogar & Moriarty 1999



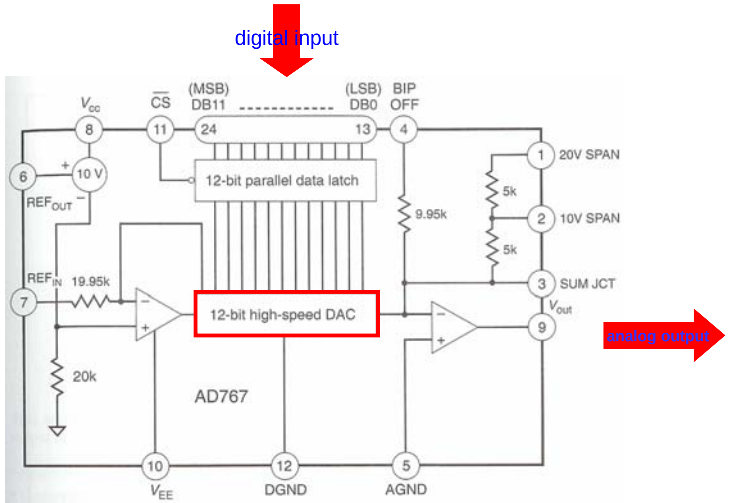
- DSP to DAC




Nekoogar & Moriarty 1999



- Digital to Analog Converter (Analog Devices, Inc.)




Nekoogar & Moriarty 1999

## Digital to Analog Converter (Analog Devices, Inc.)

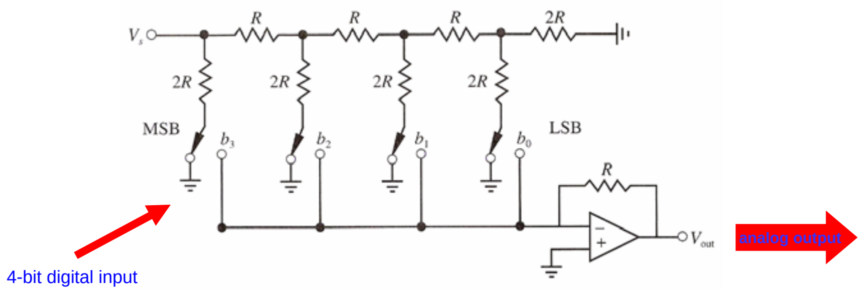
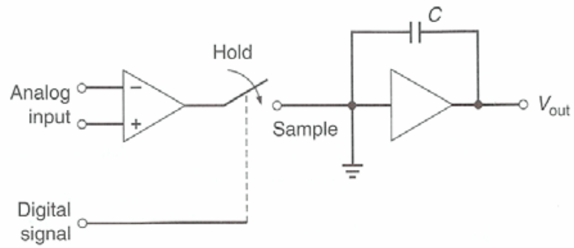



**Figure 8.11** 4-bit resistor ladder D/A converter.

Alciatore & Histand 2003



## Sample-and-Hold device




Nekoogar & Moriarty 1999



1. Timing Analysis
   - Transport time
   - Transmission time
   - Execution time
   - Processing time
   - Period
   - Deadline

2. Scheduling of
   - Jobs
   - Tasks
   - Processes
   - Memory
     - Single/Multiple Processor
     - Single/Multiple Comm Net

3. System Analysis
   - Stability
   - Performance

4. Analysis
   - Time-Delay Systems

5. Design
   - Time-Delay Control