Lecture 02
Introduction

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NTU-EE
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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

Introduction: Analog Control Systems

Franklin, Powell, Emami-Naeini 2002

Figure 1.1. The centrifugal governor (a), developed in the 1740s, was an early model of the successful Watt steam engine (b), which fueled the industrial revolution. Papers courtesy of Cambridge University.

Murray 2002
Introduction: Digital Control Systems

Murray 2002

Introduction: Distributed, Networked Control Systems

Astrom & Wittenmark 1997

Topics on Real-Time Systems

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

From Real-Time Systems by Liu 2000

Air Traffic Control

- Guidance and control
- Real-time control and command

From Real-Time Systems by Liu 2000
### Radar Signal Processing
- Tracking: gating and data association

![Diagram of radar signal processing and tracking system](image)

**FIGURE 1-6** Radar signal processing and tracking system.

### Real-Time Databases

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Air traffic control</td>
<td>20,000</td>
<td>0.50 ms</td>
<td>5.00 ms</td>
<td>3.00 sec.</td>
<td>6.00 sec.</td>
<td>12 hours</td>
</tr>
<tr>
<td>Aircraft mission</td>
<td>3,000</td>
<td>0.05 ms</td>
<td>1.00 ms</td>
<td>0.05 sec.</td>
<td>0.20 sec.</td>
<td>4 hours</td>
</tr>
<tr>
<td>Spacecraft control</td>
<td>5,000</td>
<td>0.05 ms</td>
<td>1.00 ms</td>
<td>0.20 sec.</td>
<td>1.00 sec.</td>
<td>25 years</td>
</tr>
<tr>
<td>Process control</td>
<td>0.38 ms</td>
<td>5.00 sec.</td>
<td>1.00 sec.</td>
<td>2.00 sec.</td>
<td>24 hours</td>
<td></td>
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</tbody>
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### 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

- 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

Research at NTUEE-NCSLab
### 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

### Basic Concept of Real-Time Control Systems

**Real-Time Control is**

- Very-Fast Control?
  
  - or
  
- Time-Critical Control?
Basic Concept of Real-Time Control Systems

- Control over Real-Time System
- Control the Real-Time System

P: plant
C: controller
S: scheduler

Course Topics

- 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

Source: InTech, Nov. 96

Source: Analog, Digital 02/28/01

Course Topics

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

actuator input

sensor output

actuator delays

sensor delays

controller

reference input

04/12/03

02/07/04
Course Topics

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

Networked Control System Block Diagram

The Design Philosophy of Control Science

- The Research Procedure in Control Science
  - Process → Model → Analysis → Design

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

- Differential eqn
- Laplace 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:

```
\[ y(t) \quad u(t) \]
```

Introduction: Digital Controller

- Digital Controller:

```
\[ y(t) \quad u(t) \]
```

Introduction: Control Systems

- Control Systems:

```
\[ u(t) \quad y(t) \]
```

Introduction: Analog and Digital Controllers

- Analog Controller:
  - Continuous-time systems

- Digital Controller:
  - Discrete-time systems
  - Sampled-data systems
  - Computer-controlled systems
  - Digital control systems
**Introduction: Discrete-Time Signals**

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

**Discrete-Time Signals**
- \(y(t)\)
- \(y_k \in D\)
- \(\{y_k\} \in R\)
- Sample
- Sampling Period: \(h\)
- Sampling Rate: \(\omega\)
- Quantization
- Hold

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**Introduction: Digital Controller**

**Digital Controller:**
- \(u(t)\) \rightarrow Process \rightarrow Controller \rightarrow \{u_k\} \(u_k \in D\)
- \(\{y_k\} \in D\)
- Computer Programs
- controller algorithm
  \[
  \{u_k\} = g(\{y_k\})
  \]

**Key Components of Digital Control Systems**

\[\text{Astrom & Wittenmark 1997}\]
Introduction: Digital Components

- Analog Servo-Control System
  - Nekoogar & Moriarty 1999

- Digital Motor Position Control System
  - Nekoogar & Moriarty 1999

- Analog to Digital Converter
  - Alciatore & Histand 2003

- 2-bit ADC circuit
  - Aciatore & Histand 2003
Introduction: Digital Components

- Analog to Digital Converter

- ADC to DSP

- DSP to DAC

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

Alciatore & Histand 2003

Nekoogar & Moriarty 1999
Introduction: Digital Components

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

![4-bit digital input](image)

\[V_{out} = \frac{\sum (V_{MSB} \times 2^k)}{\sum (2^k)}\]

*Figure 6.11 4-bit resistor ladder DA converter.*

- Sample-and-Hold device

![Sample-and-Hold device](image)

Introduction: Digital Components

Key Elements in Real-Time Control Systems

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