Software Engineering/Mechatronics 3DX4

Slides 10: Introduction to Digital Control Systems

Dr. Ryan Leduc

Department of Computing and Software
McMaster University

Material based on *Control Systems Engineering* by N. Nise and *Discrete-time Control Systems* by Katsuhiko Ogata

Introduction

- Digital computers perform two main tasks:
  1. Supervisor tasks outside of the control loop such as scheduling tasks, monitoring for out-of-range values, and initiating shutdowns for safety purposes.

  2. Control tasks within the feedback loop such as replacing an analog implementation of a cascade compensator.
- Essentially, we will be focusing on taking the transfer function representing a cascade compensator such as a PID controller and replacing it with a digital controller running an algorithm that emulates the physical analog controller.

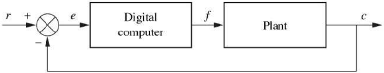


Figure 13.2a.

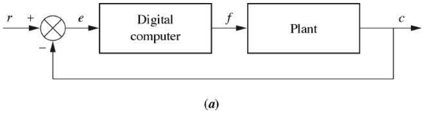
Advantages of Digital Computer

1. Reduced cost: Today's control applications often control numerous loops at the same time, each requiring an analog controller. A single digital computer can control multiple loops at once.

2. Flexibility:
   - Can replace banks of equipment, knobs, and dials with a single computer terminal.
   - Implementing a new controller is now a matter of software, not hardware modifications.
   - Information about outputs and settings now given via a graphical interface on the computer screen.
3. Noise immunity: by virtue of their implementation method, digital controllers have more noise immunity than analog systems.

Converting Between Analog and Digital

- In a physical systen, signals such as e and f are usually analog signals.
- Digital computer can only handle binary numbers, so analog signals such as e need to be converted into a sequence of binary numbers.
- Digital computers only produce sequences of binary numbers as outputs, so outputs have to be converted back into analog signals (such as output f) to go back into the physical plant.



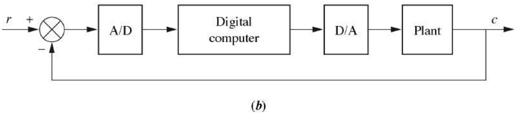


Figure 13.2.

Digital to Analog Conversion

- A digital-to-analog converter is a device that converts digital signals (binary numbers) to analog signals.
- To do this, appropriately weighted voltages are summed together to achieve the desired output voltage.
- For example, if the digital signal applied below was 110_2, the analog signal outputted would be 6V.
- Switches are electronic and set by the binary number output by the computer. Effectively instantaneous.

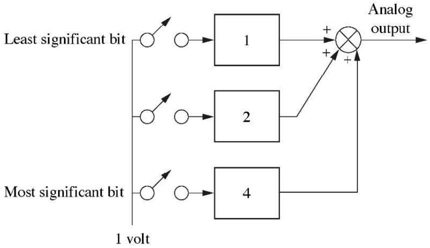


Figure 13.3.

Analog to Digital Conversion

- An analog-to-digital (A/D) converter is a device that converts analog signals to digital signals (binary numbers).
- This is a two step process, and there is a delay between the input voltage being sampled and the output binary number.
- For conversion, we first sample the analog signal, then convert it to a stream of digital numbers which is the digital signal.

Analog to Digital Conversion - II

- The analog signal is sampled periodically and held constant over the sampling interval by means of a zero-order sample-and-hold (z.o.h.) device.
- The analog signal must be held constant while digitizing as the device uses a digital counter to convert the voltage, and it takes time to reach correct binary number.

- Finally, the A/D converts the sampled number to a binary number.

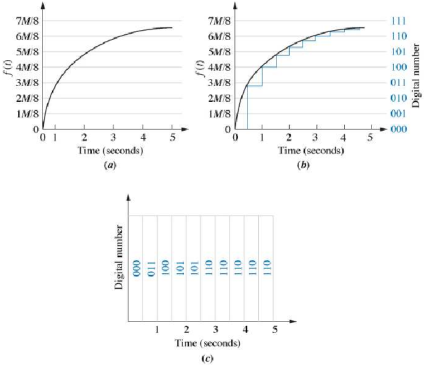


Figure 13.4

Minimum Sampling Frequency

- We need to ensure that when we convert analog signal to a digital one, that we are not losing any important information.
- Theorem below says that if we sample fast enough, we can always reconstruct original analog signal.

Theorem (Sampling)

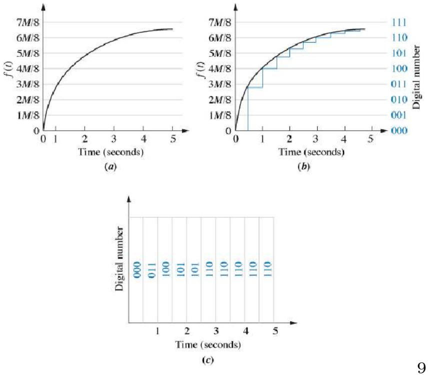
For continuous signal $x(t)$, let f_1 be the frequency of the highest frequency component that $x(t)$ contains. Let $f_s = 1/T$, where T is the sampling period being used.

If $f_s > 2f_1$ then $x(t)$ can be reconstructed completely from the sampled signal.

- For a given sampling frequency f_s, we refer to $f_N = 1/2f_s$ as the Nyqust frequency.

Quantization

- In the A/D, the dynamic range of the input signal is divided into discrete levels.
- Each level is assigned a binary number.
- If M is the maximum input voltage, then $M/2^n$ is the difference between quantization levels.



- Except boundary voltages such as $M/2^n$ and $2M/2^n$, there will be an error, called quantization error, for each digitized value.
- If we round to next higher/lower level, the max error is $(1/2)(M/2^n) = M/2^{n+1}$.

Figure 13.4