Overview of Digital Signal Processing (DSP)

Chapter Intended Learning Outcomes:

(i) Understand basic terminology in DSP

(ii) Differentiate DSP and analog signal processing

(iii) Describe basic DSP application areas
**Signal:**

- Anything that conveys information, e.g.,
  - Speech
  - Electrocardiogram (ECG) (心電圖)
  - Radar pulse
  - DNA sequence
  - Stock price
  - Code division multiple access (CDMA) signal
  - Image
  - Video
Fig. 1.1: Speech
Fig. 1.2: ECG
Fig.1.3: Transmitted & received radar waveforms
Radar transceiver sends a 1-D sinusoidal pulse at time 0

It then receives echo reflected by an object at a range of \( R \)

Reflected signal is noisy and has a time delay of \( \tau \) which corresponds to round trip propagation time of radar pulse

Given the signal propagation speed, denoted by \( c \), \( \tau \) is simply related to \( R \) as:

\[
\tau = \frac{2R}{c} \quad (1.1)
\]

As a result, the radar pulse contains the object range information
Can be a function of one, two or three independent variables, e.g., speech is 1-D signal, function of time; image is 2-D, function of space; wind is 3-D, function of latitude, longitude and elevation

- 3 types of signals that are functions of time:
  - **Continuous-time** (analog) \( x(t) \): defined on a continuous range of time \( t \), amplitude can be any value
  - **Discrete-time** \( x(nT) \): defined only at discrete instants of time \( t = \cdots - T, 0, T, 2T, \cdots \), amplitude can be any value
  - **Digital** (quantized) \( x_Q(nT) \): both time and amplitude are discrete, i.e., it is defined only at \( t = \cdots - T, 0, T, 2T, \cdots \) and amplitude is confined to a finite set of numbers
Fig. 1.4: Relationships between $x(t)$, $x(nT)$ and $x_Q(nT)$
\( x(nT) \) at \( n = 0 \) is close to 2 and \( x_Q(0) = 2 \)

\( x(nT) \in (3, 4) \) at \( n = 1 \) and \( x_Q(T) = 3 \)

Using 4-bit representation, \( x_Q(0) = 0010 \) and \( x_Q(T) = 0011 \), and in general, the value of \( x_Q(nT) \) is restricted to be an integer between \(-8\) and \(7\) according to the two’s complement representation.

In digital signal processing (DSP), we deal with \( x_Q(nT) \) as it corresponds to computer-based processing. Throughout the course, it is assumed that \textit{discrete-time signal} = \textit{digital signal}, or the quantizer has infinite resolution.
**System:**

- Mathematical model or abstraction of a physical process that relates **input** to **output**, e.g.,
  - Grading system: inputs are coursework and examination marks, output is grade
  - Squaring system: input is 5, then the output is 25
  - Amplifier: input is $\cos(\omega t)$, then output is $10\cos(\omega t)$
  - Communication system: input to mobile phone is voice, output from mobile phone is CDMA signal
  - Noise reduction system: input is a noisy speech, output is a noise-reduced speech
  - Feature extraction system: input is $\cos(\omega t)$, output is $\omega$
- Any system that processes digital signals is called a digital system, digital filter or digital (signal) processor
Processing:

- Perform a particular function by passing a signal through system

**Fig. 1.5: Analog processing of analog signal**

**Fig. 1.6: Digital processing of analog signal**
Advantages of DSP over Analog Signal Processing

- Allow development with the use of PC, e.g., MATLAB
- Allow flexibility in reconfiguring the DSP operations simply by changing the program
- Reliable: processing of 0 and 1 is almost immune to noise and data are easily stored without deterioration
- Lower cost due to advancement of VLSI technology
- Security can be introduced by encrypting/scrambling
- Simple: additions and multiplications are main operations
DSP Application Areas

- **Speech**
  - Compression (e.g., LPC is a coding standard for compression of speech data)
  - Synthesis (computer production of speech signals, e.g., text-to-speech engine by Microsoft)
  - Recognition (e.g., PCCW’s 1083 telephone number enquiry system)
  - Enhancement (e.g., noise reduction for a noisy speech)

- **Audio**
  - Compression (e.g., MP3 is a coding standard for compression of audio data)
- Generation of music by different musical instruments such as piano, cello, guitar and flute using computer
- Song with low-cost electronic piano keyboard quality
- Automatic music transcription (writing a piece of music down from a recording)

Image and Video
- Compression (e.g., JPEG and MPEG are coding standards for image and video compression, respectively)
- Recognition such as face, palm and fingerprint
- Enhancement

- Construction of 3-D objects from 2-D images

- Animation, e.g., “Avatar (阿凡達)”
- **Communications**: encoding and decoding of digital communication signals

- **Astronomy**: finding the periods of orbits

- **Biomedical Engineering**: medical care and diagnosis, analysis of ECG, electroencephalogram (EEG), nuclear magnetic resonance (NMR) data

- **Bioinformatics**: DNA sequence analysis, extracting, processing, and interpreting the information contained in genomic and proteomic data

- **Finance**: market risk management, trading algorithm design, investment portfolio analysis