Chapter 1

Introduction to Digital Signal Processing

1. Introduction

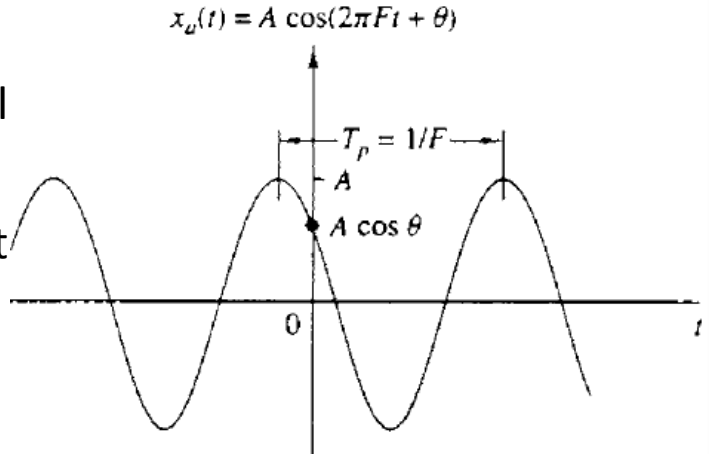
Signal processing is a discipline concerned with the acquisition, representation, manipulation, and transformation of signals required in a wide range of practical applications.

1.1 Definition of Signal

- Signal is defined as any physical quantity (phenomenon that contains a useful information) that varies as a function of time, space, or any other variable or variables.
- Signals play an important role in our life.
- A **digital signal processor** (**DSP**) is a specialized microprocessor, with its architecture optimized for the operational needs of digital signal processing.
- Digital signal processing (DSP) technology has dramatically impacted our modern society (digital/Internet audio and video, digital recording, CD, DVD, and MP3 players, iPhone and iPad, digital cameras, digital and cellular telephones, digital satellite and TV, wired and wireless networks). Medical instruments (ECG, digital X-rays, medical image systems).

1.2 Classification of signals

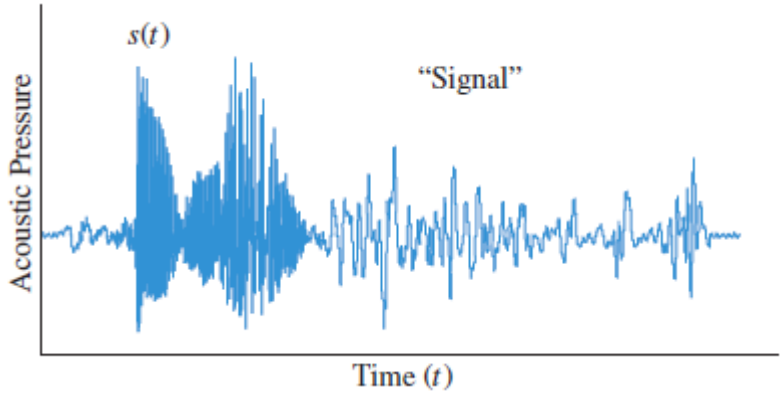
- A signal can be One-dimensional (1-D) (example: speech signal $y=(t)$) or two-dimensional (2-D) (example: grayscale image $y=f(x,y)$) or Multi-Dimensional (M-D RGB image).
- A signal can be Stochastic (signals take random values at any given time instant and must be modeled probabilistically) or deterministic (completely specified functions of time).
- A signal can be periodic or aperiodic,
- A signal can be continuous or discrete (in time and amplitude).



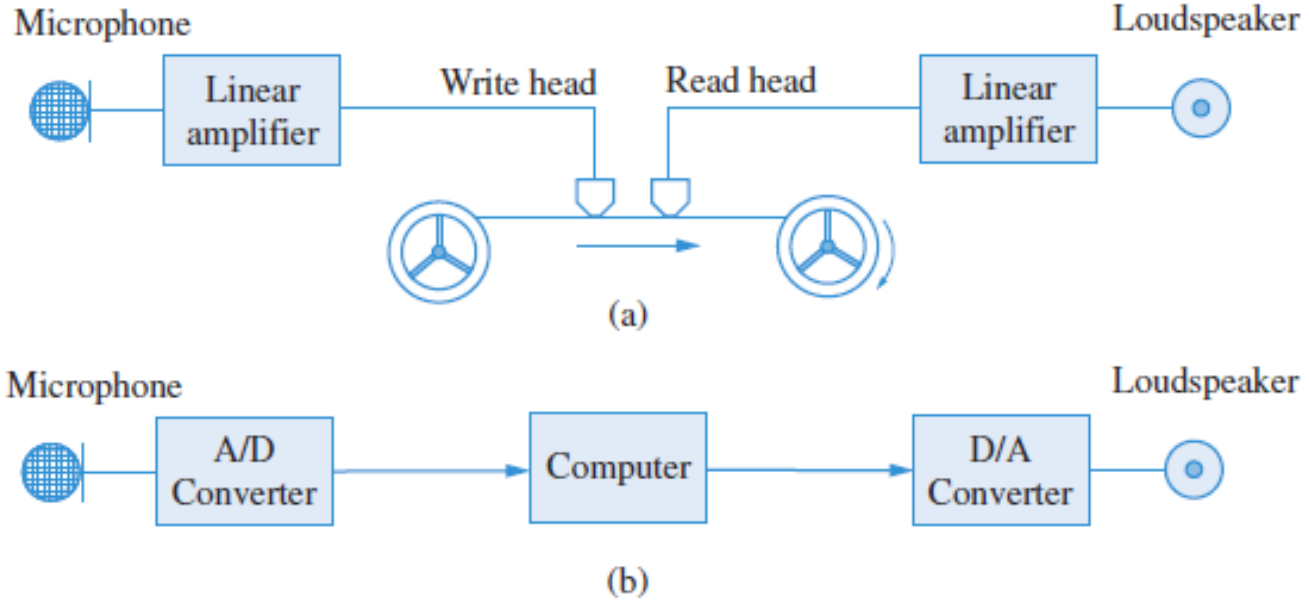
2 Example of signals

- **Speech Signal (1D signal).**

  - Sound waves are picked up by a microphone and converted to a small analog voltage called the audio signal.
  - In the figure: Example of a recording of speech. The time waveform shows the variation of acoustic pressure as a function of time.



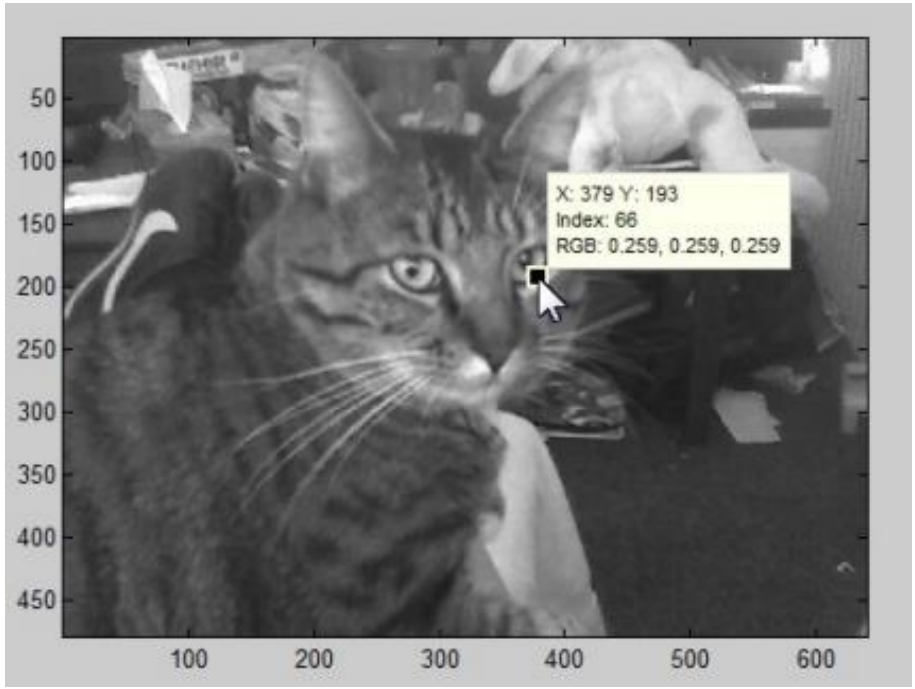
  - Block diagrams of: (a) an analog audio recording system using magnetic tape.
    (b) a digital recording system using a personal computer.



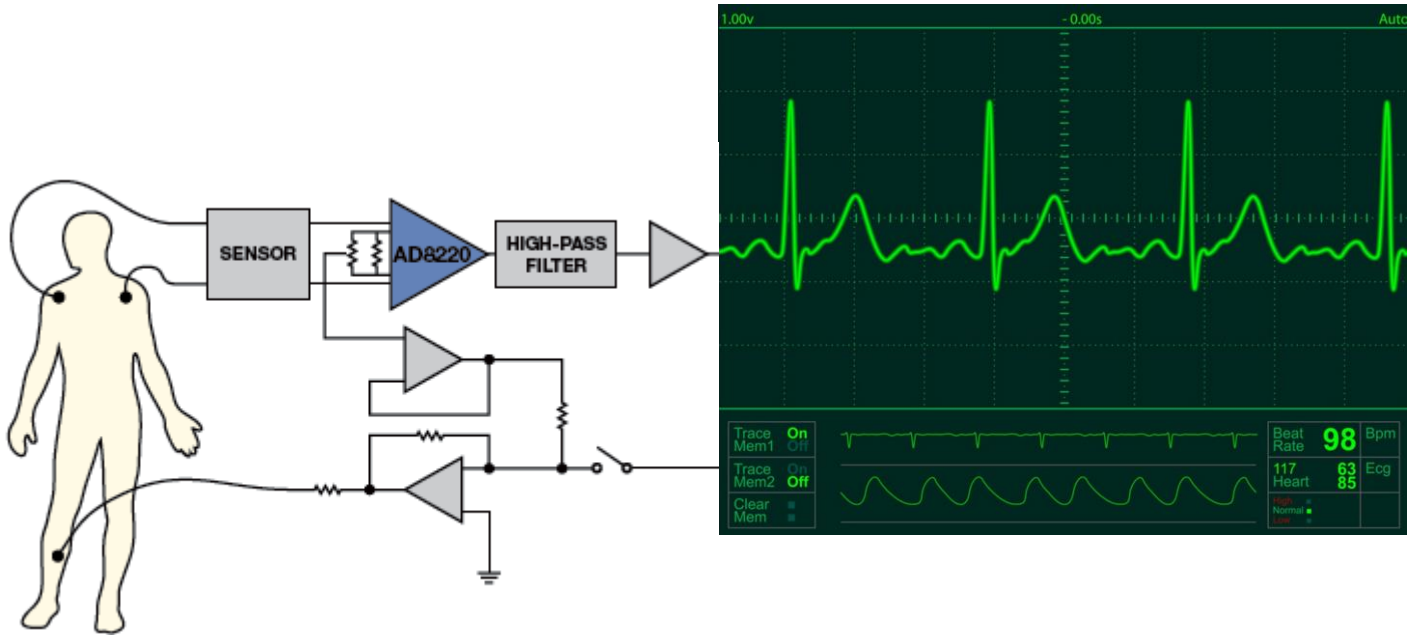
2 Example of signals Continued

- **Image (2D signal)**

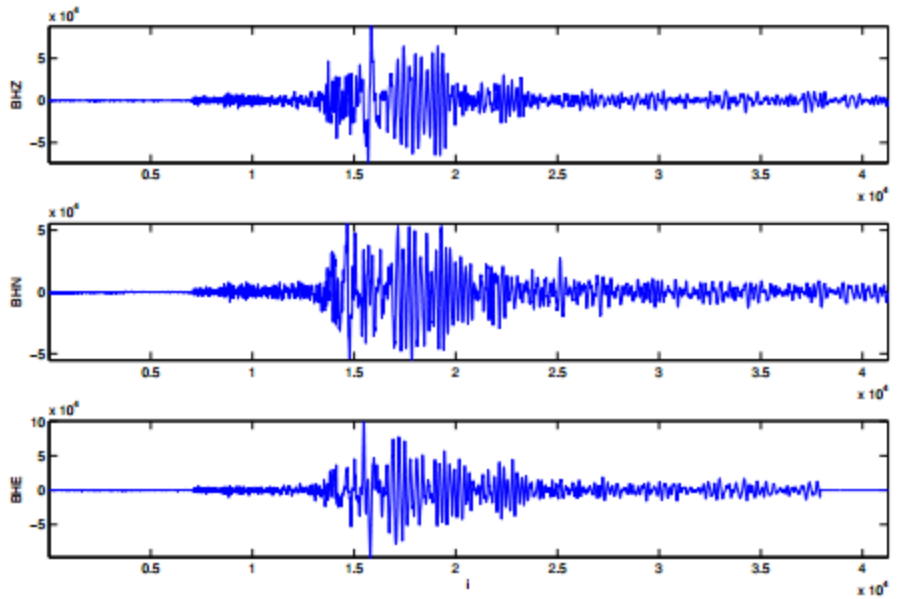
Image can be seen as a Matrix signal where the variation of the levels of gray scale embedded an information.



- **ECG Signals: (Continuous-time signal)**



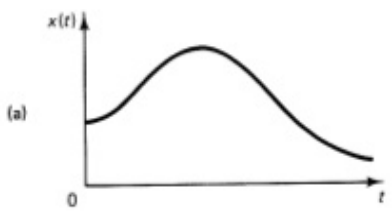
- **Seismic Signals: (Continuous-time signal)**



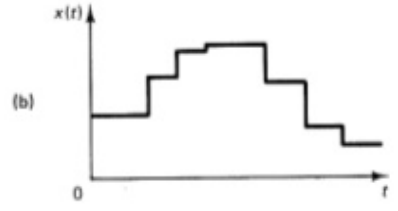
Seismogram captured at "Elk" station in the Rocky Mountain Sensing Network

- **Discrete-time signals:**

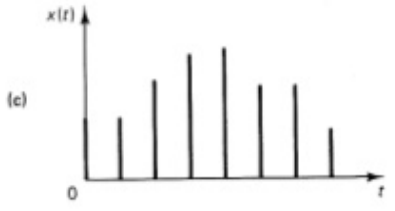
- Variation of the petrol prices in the world market,
- Variation of the newborns in given region,
- Stock variations in given country.



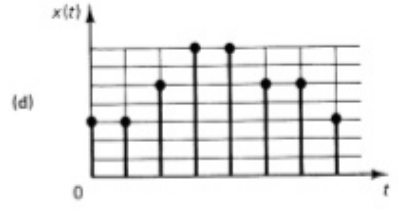
Continuous-time analog signal



Continuous-time quantized signal



Sampled data signal

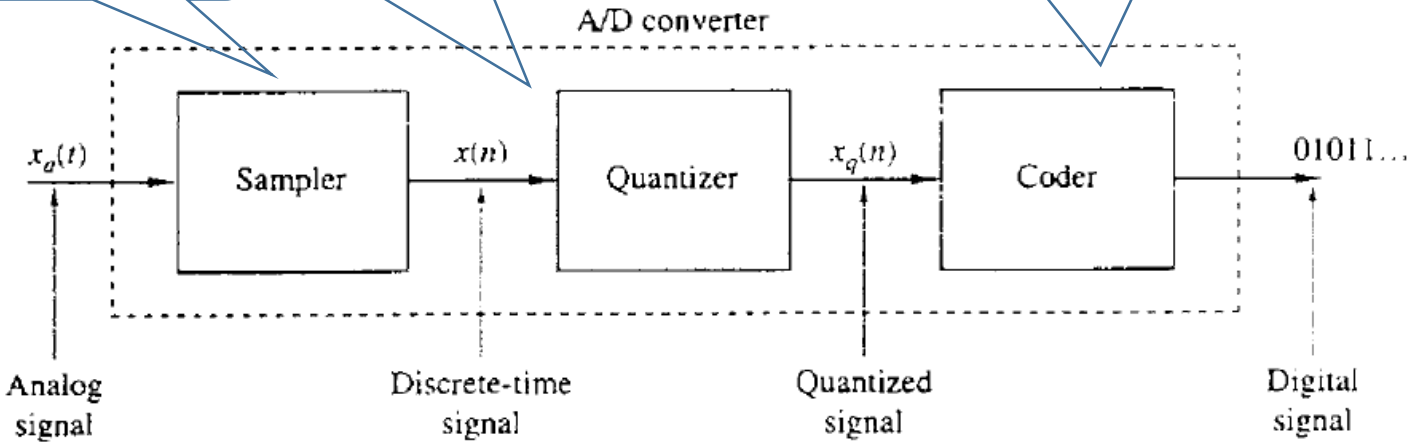


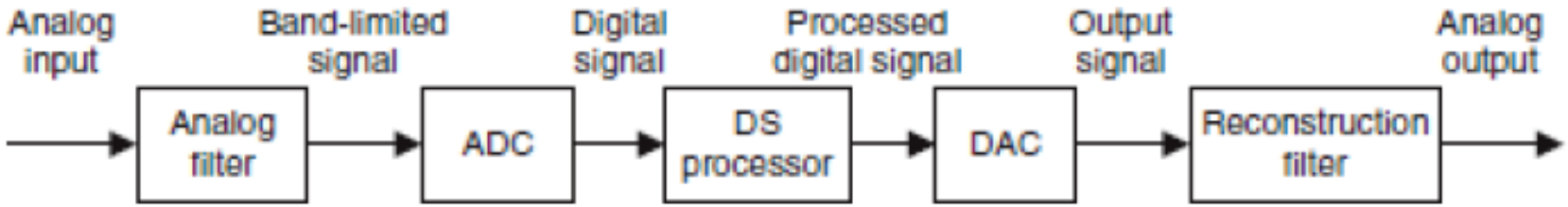
Digital signal

Taking samples of continuous-time signal at discrete-time instants

Value of each signal sample is represented by a value selected from a finite set of possible values

Each discrete value $x_q(t)$ is represented by b-bits binary sequence





A digital signal-processing scheme:

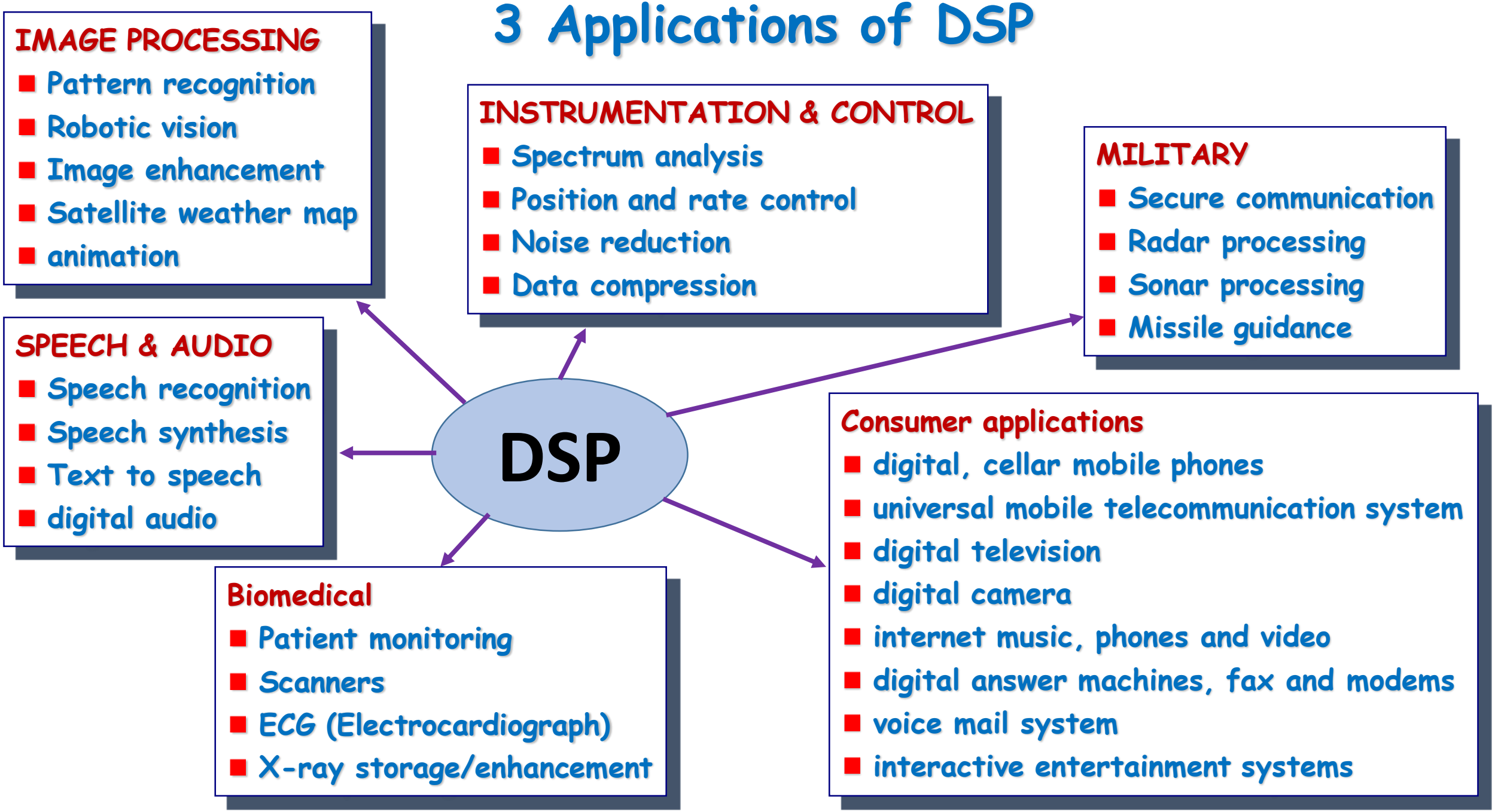
- **Deterministic and random signals**

  - The behavior of deterministic signals is completely predictable, whereas the behavior of random signals has some degree of uncertainty associated with them.

  - If we know all past values of a signal up to the present time, and by using the past values, we can predict the future values of the signal exactly, we say that the signal is *deterministic*.

  - On the other hand, if we cannot predict the future values of the signal exactly, we say that the signal is *random*.

3 Applications of DSP



4 Signal Processing

- **Representation, transformation** and **manipulation** of signals and the information they contain.

- **Signal operation include:**

  (1) Transform, filter, inspection, spectrum analysis;

  (2) Modulation and coding;

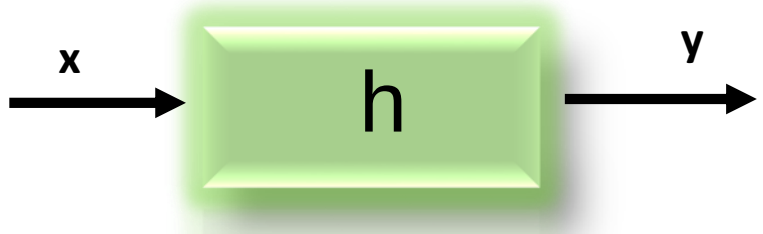
  (3) Analog Signal Processing;

  (4) Digital Signal Processing.

- **Time-domain and Frequency domain:** The signals are in nature in time domain. In time domain the signal y(t) is evaluated according to the progression of its state or amplitude with time. In Frequency domain, we use the signal amplitude versus its corresponding frequency for the time being, (obtained from fast Fourier transform (FFT) DSP algorithm).

5 Basic digital signal processing examples

5.1 Basic concepts about system



(1) **System** Device or technology of signal processing.

(2) **Analog system** System with analog input and output.

(3) **Digital system** System with digital input and output.

Three Problems

Given x and h, find y analysis
Given h and y, find x control
Given x and y, find h design or synthesis

5.2 Processing of analog signal with digital methods

(1) Digitalized process for analog signals

(2) Digital processing method

5.3 Feature of Digital System

Advantages

(1) High accuracy: Floating point 8,16,32,64 bits

The ability to consistently perform required function without degradation or failure.

(2) High reliability: VLSI (analog: drift, calibration)

(3) Flexible: DSP, Software, FPGA, VHDL

easier to store, transmit and manipulate information

(4) Easy to integrate

(5) Deal with high dimensional signals

(6) Low costs: reusable, reconfigurable

cheaper device and easier to design

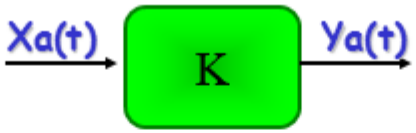
(7) Data logging (Recording)

(8) Adaptive capability

The digital systems can be used for different applications by simply changing the program without additional changes in hardware.

Disadvantages

Complex: cost, speed and quantization error during analog signal sampling.



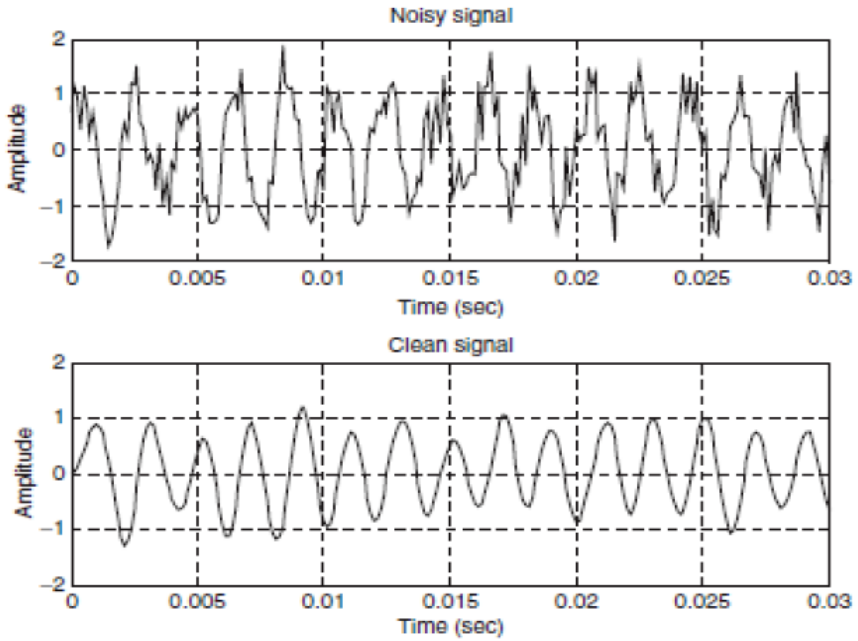
Analog Signal Processing

Digital Signal Processing

5.4 digital signal processing examples

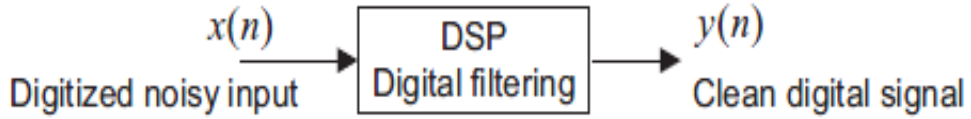
- **Digital Filtering:**

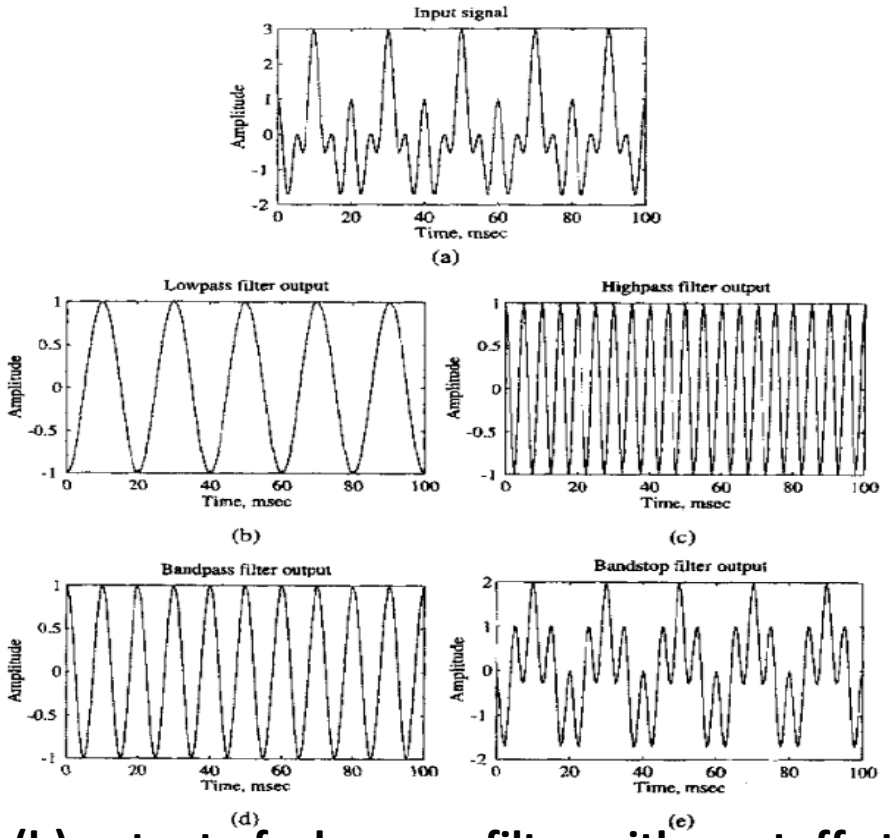
A digitized noisy signal is ***x (n)*** contains a useful low-frequency signal and noise that occupies all of the frequency range. The input signal ***x (n)*** can be enhanced using digital filtering (the high-frequency components in the signal are considered noise).



Top: noisy signal. ***Bottom***: clean signal (using digital low-pass filter)

Simple digital filtering block

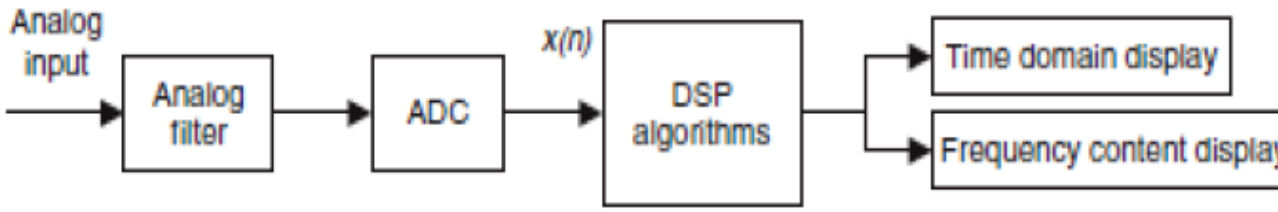




(a) input signal, (b) output of a lowpass filter with a cutoff at 80 Hz, (c) output of a highpass filter with a cutoff at 150 Hz, (d) output of a bandpass filter with a cutoffs at 80 Hz and 150 Hz, and (e) output of a bandstop filter with cutoffs at 80 Hz and 150 Hz.

- ## Signal Frequency (Spectrum) Analysis:

Fourier transform is used to convert any given signal (continuous or discrete) to the frequency domain.



Signal spectral analysis

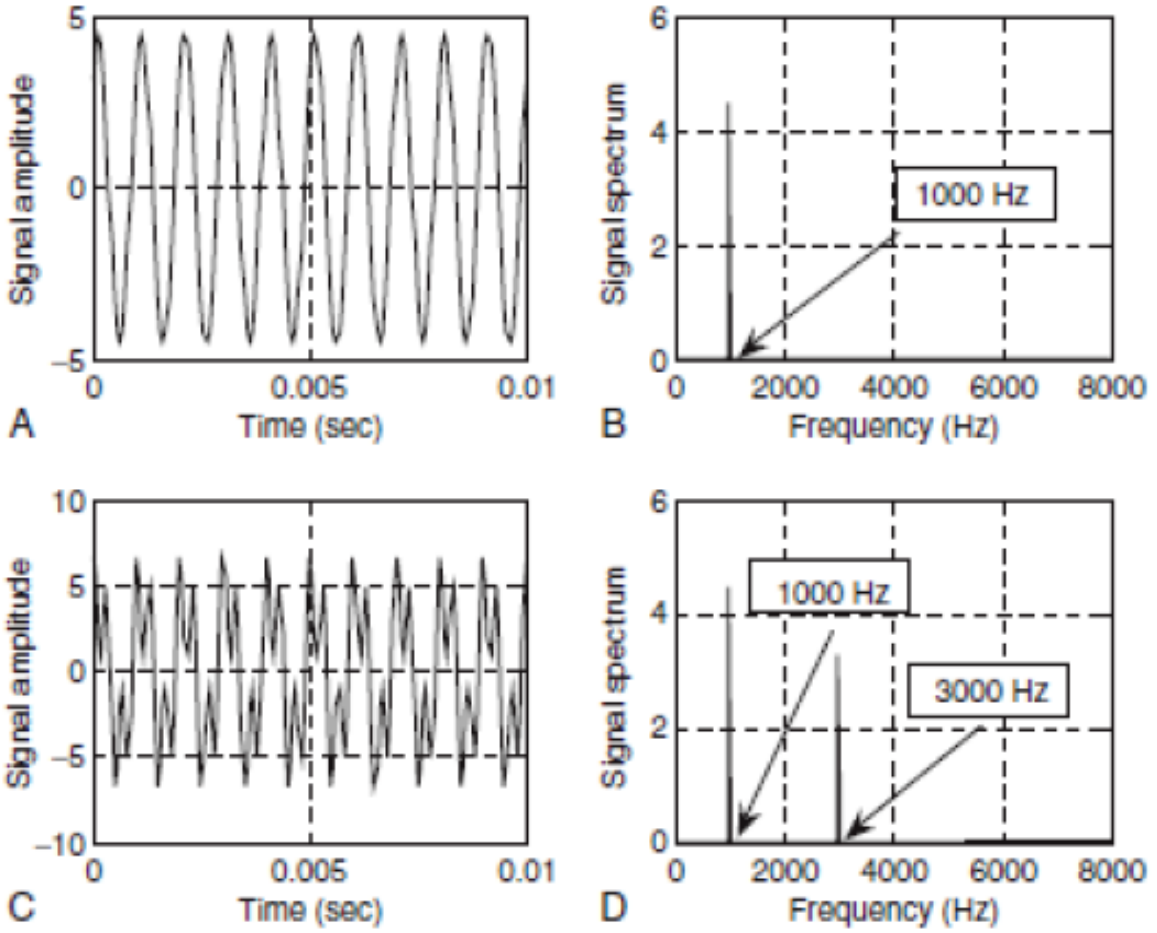
Audio signals and their spectrums

- Figure A is a time domain display of the recorded audio signal with a frequency of 1,000 Hz sampled at 16,000 samples per second.

- Figure B displays the calculated signal spectrum versus frequency, in which the peak amplitude is clearly located at 1,000 Hz.

- Figure C shows a time domain display of an audio signal consisting of one signal of 1,000 Hz and another of 3,000 Hz sampled at 16,000 samples per second.

- Figure D gives two locations (1,000 Hz and 3,000 Hz) where the peak amplitudes reside, hence the frequency content display presents clear frequency information of the recorded audio signal.



- ## Digital Photo Image Enhancement

Digital image enhancement is another example of signal processing in two dimensions. Due to the weather conditions, the image in figure (a) was improperly exposed in natural light and came out dark. The image processing technique called **histogram equalization** is used to increase image contrast (stretch the light intensity of the image) so that detailed information in the image can easily be see, figure (b).

(a) Original image

(b) Enhanced image

- **MORE APPLICATIONS**

The DSP compresses the digital signals and removes background noise.

When you speak, your voice is picked up by an analog sensor in the cell phone's microphone

An analog-to-digital converter chip converts your voice, which is an analog signal, into digital signals, represented by 1s and 0s.

In the listener's cell phone, a digital-to-analog converter chip changes the digital signals back to an analog voice signal.

Your voice exits the phone through the speaker.