Chapter 1

Signals and Signal Processing

Contents

1. Overview of DSP

- Signals play an important role in our daily life
- A signal is a function of independent variables such as time, distance, position, temperature, and pressure
- A signal carries information
- The objective of signal processing is to extract the useful information carried by the signal

1. Overview of DSP

- Method information extraction: Depends on the type of signal and the nature of the information being carried by the signal
- DSP is concerned with the mathematical representation of the signal and the algorithmic operation carried out on it

1. Overview of DSP

- Signals can be represented in the domain of the original independent variables or in a transformed domain
- Likewise, the information extraction process may be carried out in the original domain of the signal or in a transformed domain

1. Overview of DSP

- This course is concerned with the discrete time representation of signals and their discrete-time processing

2. Classification of Signals

Types of signals

- Depends on the nature of the independent variables and the value of the function defining the signal.

2. Classification of Signals

- Continuous versus Discrete
- Real versus Complex
- Scalar versus Vector
- One dimensional versus Multi-Dimensional
- Deterministic versus Random

2. Classification of Signals

Examples

- The speech signal is an example of a 1-D signal where the independent variable is time
- An image signal, such as a photograph, is an example of a 2-D signal where the 2 independent variables are the 2 spatial variables

2. Classification of Signals

- A color image signal is composed of three 2-D signals representing the three primary colors: red, green and blue (RGB)
- The 3 color components of a color image are shown in the next slide

2. Classification of Signals

Red component

Green component

Blue component

2. Classification of Signals

- The full color image obtained by displaying the previous 3 color components is shown below

2. Classification of Signals

- For a 1-D signal, the independent variable is usually labeled as time
- In this case, signals can be classified into continuous-time signals and discrete-time signals (sequence of numbers)
- A continuous-time signal with a continuous amplitude is usually called an analog signal

2. Classification of Signals

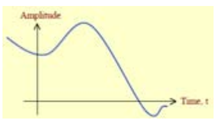
- A discrete-time signal with discrete-valued amplitudes represented by a finite number of digits is referred to as the digital signal
- A discrete-time signal with continuous valued amplitudes is called a sampled-data signal

2. Classification of Signals

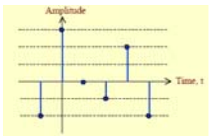
- A digital signal is thus a quantized sample data signal
- A continuous-time signal with discrete value amplitudes is usually called a quantized boxcar signal (量化矩形信号)
- The figure in the next slide illustrates the 4 types of signals

2. Classification of Signals

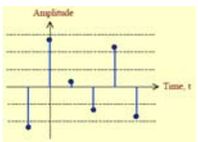
(a) A continuous-time signal



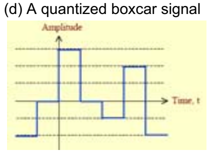
(b) A digital signal
(quantized sample data signal)



(c) A sampled-data signal



(d) A quantized boxcar signal



3. Representation of Signals

- For a continuous-time 1-D signal, the continuous independent variable is usually denoted by t
- For example, $u(t)$ represents a continuous time 1-D signal
- For a discrete-time 1-D signal, the discrete independent variable is usually denoted by n

3. Representation of Signals

- For example, $\{v(n)\}$ represents a discrete time 1-D signal
- Each member, $v(n)$, of a discrete-time signal is called a sample
- In many applications, a discrete-time signal is generated by sampling a parent continuous-time signal at uniform intervals of time

3. Representation of Signals

- If the discrete instants of time at which a discrete-time signal is defined are uniformly spaced, the independent discrete variable *n* can be normalized to assume integer values

4. Typical Signal Processing Operations

- Most signal processing operations in the case of analog signals are carried out in the time-domain
- In the case of discrete-time signals, both time-domain or frequency-domain operations are usually employed

4.1 Elementary Time-Domain Operations

- Three most basic time-domain signal operations are scaling, delay, and addition
- Three other elementary operations are integration , differentiation and product
- More complex operations are implemented by combining two or more elementary operations

4.2 Filtering

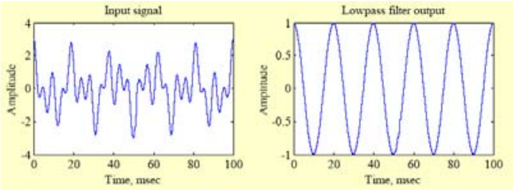
- Filtering is one of the most widely used complex signal processing operations
- Filtering is used to pass certain frequency components in a signal through the system without any distortion and to block other frequency components

4.2 Filtering

- The range of frequencies that is allowed to pass through the filter is called the passband, and the range of frequencies that is blocked by the filter is called the stopband
- Several typical filters are lowpass, highpass, bandpass, bandstop filters
- An important term associated with filtering is cutoff frequency (3dB cutoff frequency)

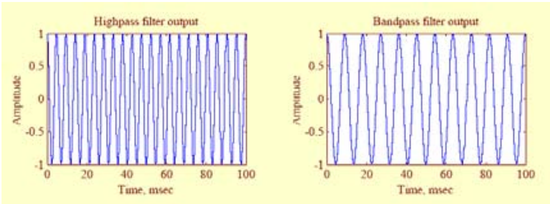
4.2 Filtering

- Figures below illustrate the lowpass filtering of an input signal composed of 3 sinusoidal components of frequencies 50 Hz, 110 Hz, and 210 Hz



4.2 Filtering

- Figures below illustrate highpass and bandpass filtering of the same input signal



4.2 Filtering

Other types of filters

- A filter blocking a single frequency component is called a notch filter
- A multiband filter has more than one passband and more than one stopband
- A comb filter blocks frequencies that are integral multiples of a low frequency

4.2 Filtering

Example

- A common source of noise is power lines radiating electric and magnetic fields
- The noise generated by power lines appears as a 60-Hz sinusoidal signal corrupting the desired signal and can be removed by passing the corrupted signal through a notch filter with a notch frequency at 60 Hz

4.3 Generation of Complex Signals

- All naturally generated signals are real-valued. In some applications, it is desirable to develop a complex signal from a real signal having more desirable properties
- A complex signal can be generated from a real signal by employing a Hilbert transformer

4.3 Generation of Complex Signals

- The impulse response of a Hilbert transformer is given by

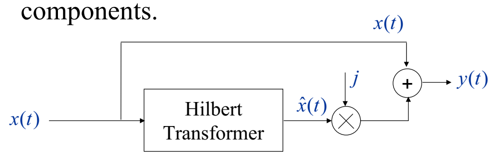
$$h_{HT}(t) = \frac{1}{\pi t}$$

- The continuous-time Fourier transform $H_{HT}(j\Omega)$ of $h_{HT}(t)$ is given by

$$H_{HT}(j\Omega) = \begin{cases} -j, & \Omega > 0 \\ j, & \Omega < 0 \end{cases}$$

4.3 Generation of Complex Signals

- The output of the system shown in the block diagram is a complex signal, also called an *analytic signal*, has only positive frequency components.



Generation of an analytic signal using a Hilbert transformer

4. Other Operations

4.4 Modulation and Demodulation

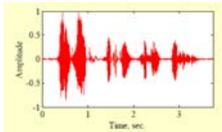
4.5 Multiplexing and Demultiplexing

4.6 Quadrature Amplitude Modulation

4.7 Signal Generation

5. Examples of Typical Signals

- Speech and music signals - Represent air pressure as a function of time at a point in space
- Waveform of the speech signal "I like digital signal processing" is shown below

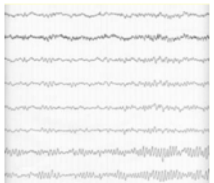


5. Examples of Typical Signals

- Electrocardiography (ECG) Signals - represent the electrical activity of the heart
- A typical ECG signal is shown below

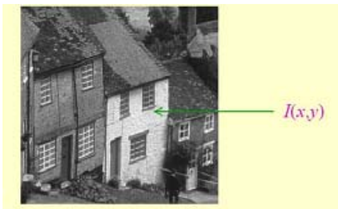
5. Examples of Typical Signals

- Electroencephalogram (EEG) Signals - Represent the electrical activity caused by the random firings of billions of neurons in the brain



5. Examples of Typical Signals

- Black-and-white picture - represents light intensity as a function of two spatial coordinates

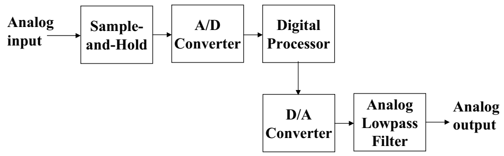


5. Examples of Typical Signals

- Video signals - Consists of a sequence of images, called frames, and is a function of 3 variables: 2 spatial coordinates and time

6. Why Digital Signal Processing

- Digital processing of an analog signal are shown below



Scheme for the digital processing of an analog signal

6. Why Digital Signal Processing

Advantages of DSP

- Absence of drift in the filter characteristics
  - Processing characteristics are fixed, e.g. by binary coefficients stored in memories
  - Thus, they are independent of the external environment and of parameters such as temperature
  - Aging has no effect

6. Why Digital Signal Processing

- Improved quality level
  - Quality of processing limited only by economic considerations
  - Arbitrarily low degradations achieved with desired quality by increasing the number of bits in data/coefficient representation
  - An increase of 1 bit in the representation results in a 6 dB improvement in the SNR

6. Why Digital Signal Processing

- Reproducibility
  - Component tolerances do not affect system performance with correct operation
  - No adjustments necessary during fabrication (加工、装配)
  - No realignment (调整) needed over lifetime of equipment

6. Why Digital Signal Processing

- Ease of new function development
  - Easy to develop and implement adaptive filters, programmable filters and complementary filters
  - Illustrates flexibility of digital techniques
- Multiplexing
  - Same equipment can be shared between several signals, with obvious financial advantages for each function

6. Why Digital Signal Processing

- Modularity
  - Uses standard digital circuits for implementation
- ...

6. Why Digital Signal Processing

Limitations of DSP

- Lesser Reliability
  - Digital systems are active devices, and thus use more power and are less reliable
- Limited range of frequencies available for processing (*why?*)

The End of Chapter 1