Tutorial

Series 2

Advanced Biomedical Signal and Image Processing

Master: Plasturgy & Biomedical Engineering

Pr. Omar ELOUTASSI

Exercise 1

1. What is the primary purpose of using a filter in signal processing?
A) To remove noise and unwanted components
B) To increase signal amplitude
C) To convert an analog signal to a digital signal
D) To change the signal's sampling rate

2 How does a high-pass filter differ from a low-pass filter?
A) A high-pass filter removes high frequencies
B) A low-pass filter removes low frequencies
C) A high-pass filter allows high frequencies to pass through
D) Both (B) and (C)

3 What type of filter is best for removing low-frequency baseline wander in ECG signals?
A) Notch Filter
B) High-pass Filter
C) Low-pass Filter
D) Band-stop Filter

4. What is the main difference between FIR and IIR filters?
A) FIR filters have feedback, IIR filters do not
B) IIR filters have feedback, FIR filters do not
C) FIR filters use recursion, IIR filters do not
D) FIR filters require fewer coefficients than IIR filters

5. What is an advantage of FIR filters over IIR filters?
A) Always more efficient than IIR filters
B) Always require fewer computations
C) Always have a linear phase response
D) Can approximate analog filters exactly

6. How do you determine the order of a digital filter?
A) By the highest power of the denominator polynomial
B) By the number of taps in an FIR filter
C) By the number of poles and zeros in the transfer function
D) All of the above

7. How does the wavelet transform differ from the Fourier transform?
A) Wavelet transform provides both time and frequency information
B) Fourier transform provides time information only
C) Wavelet transform does not decompose signals into frequencies
D) Both are exactly the same

8. What is a major application of wavelet transform?
A) Image compression
B) DC voltage regulation
C) Digital modulation
D) Time-domain convolution

O. ELOUTASSI: o.eloutassi@umi.ac.ma

9. Why is multi-resolution analysis useful in wavelet transform?
A) It allows for zooming into different frequency components
B) It improves the speed of the Fourier Transform
C) It enhances the power spectrum
D) It only works for stationary signals

10. What is the delta function δ[n]\delta[n]δ[n] in discrete-time signals?
A) A unit step function
B) A function that is 1 for n=0n = 0n=0 and 0 otherwise
C) A function used only in Fourier analysis
D) A function that is 1 for all nnn

11. How is the delta transform used in signal processing?
A) To transform discrete signals into the frequency domain
B) To simplify difference equations
C) To represent impulse responses
D) All of the above

12. What is the region of convergence (ROC) in Z-transform analysis?
A) The region where the Fourier series converges
B) The set of values for which the Z-transform is finite
C) The area in a Fourier transform plot
D) The phase response of a signal

13. What is a notch filter commonly used for?
A) Removing high-frequency noise
B) Removing a specific frequency band
C) Amplifying low frequencies
D) Removing low-frequency noise

14. What type of noise does a 60 Hz Notch Filter remove from an EEG signal?
A) Muscle artifact noise
B) Power line interference
C) Electrode movement noise
D) High-frequency noise

15. How does a notch filter affect the frequency response of a signal?
A) It amplifies all frequencies equally
B) It removes a specific frequency while preserving others
C) It increases the overall power of the signal
D) It applies a low-pass filtering effect

16. What does the Fourier Transform do?
A) Converts a signal into the time domain
B) Converts a time-domain signal into its frequency components
C) Increases the amplitude of a signal
D) Reduces the length of a signal

17. What is the difference between the Fourier Transform and the Laplace Transform?
A) Fourier Transform is used only for continuous signals

O. ELOUTASSI: o.eloutassi@umi.ac.ma

B) Laplace Transform includes complex frequency analysis
C) Fourier Transform cannot be applied to biomedical signals
D) There is no difference

18. How does the DTFT differ from the DFT?
A) DTFT is continuous, DFT is discrete
B) DTFT is computed only for finite-length signals
C) DTFT is periodic in time
D) DFT and DTFT are identical

19. How does the sampling frequency affect the DTFT spectrum?
A) Higher sampling frequency reduces aliasing
B) Lower sampling frequency improves resolution
C) Sampling frequency has no effect on DTFT
D) DTFT works only at Nyquist rate

20. What is the advantage of using FFT instead of DFT?
A) FFT is faster and computationally efficient
B) FFT provides more accurate results
C) FFT requires fewer memory resources
D) Both (A) and (C)

21. How is the DFT matrix constructed?
A) Using exponential functions
B) Using sine and cosine functions
C) Using convolution operations
D) By applying Laplace Transform

22. What are the two main properties of a Linear Time-Invariant (LTI) system?
A) Linearity and Stability
B) Time-invariance and Causality
C) Linearity and Time-invariance
D) Causality and Boundedness

23. How can convolution be used to analyze LTI systems?
A) It determines the system's frequency response
B) It finds the system's impulse response
C) It calculates the system's stability
D) It is not used for LTI analysis

24. Why is the impulse response important in LTI systems?
A) It determines how the system behaves for all inputs
B) It is only useful for continuous-time signals
C) It cannot be used for FIR filters
D) It is only used in electrical circuits

Exercise2 Quiz Questions:

1. What is the primary purpose of using a filter in digital signal processing?

O. ELOUTASSI: o.eloutassi@umi.ac.ma

2. How does a high-pass filter differ from a low-pass filter in terms of frequency response?
3. What are the main types of filters used in signal processing?
4. What are the key differences between FIR and IIR filters?
5. What is the main advantage of FIR filters over IIR filters?
6. How do you determine the order of a digital filter?
7. How does the Wavelet Transform differ from the Fourier Transform?
8. What are the applications of Wavelet Transform in biomedical signal processing?
9. What is the advantage of multi-resolution analysis in wavelet transform?
10. What is the unit impulse function $\delta[n]$?
11. How is the Delta Transform used in discrete-time signal analysis?
12. What is the difference between the Delta Transform and the Fourier Transform?
13. What is the relationship between the DTFT and the DFT?
14. How does the sampling frequency affect the DTFT spectrum?
15. What is the significance of the DTFT's periodicity?
16. What is a Notch Filter used for in biomedical signal processing?
17. How does a Notch Filter affect the frequency response of a signal?
18. What are some real-world applications of Notch Filters?
19. What is the main difference between the Fourier Transform **a**nd the Laplace Transform**?**
20. How does the Fourier Transform represent signals in the frequency domain?
21. What is the significance of the magnitude and phase spectra?
22. What is the primary difference between the DTFT and DFT?
23. What is the advantage of using FFT over DFT?
24. How is the DFT matrix constructed?
25. What are the two main properties of a Linear Time-Invariant (LTI) system?
26. How can convolution be used to analyze LTI systems?
27. What is the significance of the impulse response?

Exercise 3: Short answer question

1. Explain the difference between analog and digital filters.
2. Why do IIR filters require feedback while FIR filters do not?
3. Describe one practical application of Wavelet Transform in bio signal.
4. Explain the significance of the unit impulse function in system analysis.
5. Why is a Notch Filter commonly used in ECG and EEG signal processing?
6. Why is the Fourier Transform useful in signal processing?
7. How does the DTFT differ from the Fourier Transform?
8. Why is the DFT always computed using the FFT algorithm?
9. How does superposition help determine if a system is linear?

O. ELOUTASSI: o.eloutassi@umi.ac.ma

Exercise 4

Design a low-pass filter with a cutoff frequency of 500 Hz for a signal sampled at 2000 Hz**.** Use an appropriate filter design method and justify your choice.

Exercise 5:

Given the difference equation of an IIR filter: $y[n] = 0.5y[n-1] + x[n] - x[n-1]$

Determine whether this filter is FIR or IIR. Then compute the output for the input sequence x[n] = {1, 2, 3, 4} assuming initial conditions are zero.

Exercises 6.

Perform a Wavelet Transform on a signal using the Haar Wavelet. Explain how wavelets provide both time and frequency resolution.

Exercise 7:

Determine Z-Transform of the sequence x[n]=δ[n]+2δ[n−1]−δ[n−2]

Where: δ[n] is the unit impulse function, which is defined as: $\delta[n] = \begin{cases} 1\ if\ n = 0 \\ 0\ otherwise \end{cases}$

Exercise 8:

Design a Notch Filter to Remove 60 Hz Power Line Interference from an EEG Signal

Such as: Signal sampled at fs=250Hz and the interference is at f=60Hz (power line frequency).

Exercise 9:

Compute the Fourier Transform of the function: $x(t) = e^{-2t}u(t)$

Where u(t) is the unit step function, $u(t) = \begin{cases} 0, t < 0 \\ 1, t \geq 0 \end{cases}$

Fourier Transform Definition: X(f) of a continuous-time signal x(t) is defined as:

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}\,dt$$

Exercise 10:

Compute the DTFT of the sequence: x[n]={1,2,3,4} and sketch its magnitude spectrum**.**

The Discrete-Time Fourier Transform (DTFT) of a sequence x[n] is defined as:

O. ELOUTASSI: o.eloutassi@umi.ac.ma

$$X(e^{j\omega}) = \sum_{n=-\infty}^{\infty} x[n]e^{-j\omega}$$

Where: $X(e^{j\omega})$ is the DTFT of the sequence x[n] an ω is the continuous frequency variable (ranging from $-\pi$ to π).

Exercise 11 :

Compute the DFT of the sequence: x[n]={0.5,0,1.0,1.5} using matrix multiplication.

The Discrete Fourier Transform (DFT) of a sequence x[n] of length N is given by the formula:

$$X[k] = \sum_{n=0}^{N-1} x[n] \cdot e^{-j\frac{2\pi}{N}kn}$$

where: X[k] is the k^{th} component of the DFT (for k=0,1,2,...,N−1), x[n] is the input sequence (for n=0,1,2,...,N−1), N is the length of the sequence.

Matrix Form of DFT:

$$X = W_N \cdot x$$

Where: X is the vector of DFT coefficients, x is the input signal vector and $W_N$is the DFT matrix of size N×N, defined as:

$$W_N = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & e^{-j\frac{2\pi}{N}} & e^{-j\frac{2\pi}{N}2} & e^{-j\frac{2\pi}{N}3} \\ 1 & e^{-j\frac{2\pi}{N}2} & e^{-j\frac{2\pi}{N}4} & e^{-j\frac{2\pi}{N}6} \\ 1 & e^{-j\frac{2\pi}{N}3} & e^{-j\frac{2\pi}{N}6} & e^{-j\frac{2\pi}{N}9} \end{bmatrix}$$

Exercise 12

Consider a system defined by the difference equation: y[n] = 0.5y[n−1]+x[n]

Determine if the system is linear and time-invariant then find the impulse response of the system.

Exercise 13

A kernel function is used in signal processing, machine learning, and convolution operations to transform data or extract specific features. Consider the following discrete-time convolution operation where a signal x[n] is filtered using a kernel h[n]:

$$y[n] = (x * h)[n] = \sum_{k=-\infty}^{\infty} x[k]h[n-k]$$

Given the discrete input signal: x[n]={1,2,3,4} and the kernel (impulse response): h[n]={1,−1,2}

1. Compute the output y[n] using the convolution sum.
2. Verify if the kernel function h[n] is symmetric (i.e., h[n]=h[−n]).
3. If the kernel function were used in a smoothing filter, what modification would you suggest?