

Design and Implementation of FIR and IIR Filters to Clean Noisy Signals Using Python

PYTHON CRT PROJECT

EEE-B/SECTION

24705A0215

Table of Contents

1. Introduction

2. Fundamentals of Digital Filters

3. FIR Filters: Theory and Design

4. IIR Filters: Theory and Design

5. Problem Statement and Objectives 6. Software and Libraries Used

7. Overview of the Python Program

8. Detailed Explanation of Code

9. Signal Generation and Noise Model 10. FIR Filter Design and Implementation 11. IIR Filter Design and Implementation 12. Applying Filters to Noisy Signal

13. Frequency Response Analysis

14. Visualization of Results

15. Performance Comparison Between FIR and IIR 16. Practical Applications

17. Extending the Project

18. Challenges and Solutions

19. Conclusion

1.Introduction

Background:-

In the field of digital signal processing (DSP), filters are used extensively to manipulate signals to enhance useful information and reduce noise or unwanted components. Many real-world signals—whether audio, biomedical, or sensor outputs—contain noise which can obscure important characteristics. Filtering is essential to improving signal quality for analysis or further processing.

Objective:-

This project focuses on two primary digital filter types: FIR (Finite Impulse Response) and IIR (Infinite Impulse Response). Using Python, SciPy, and Matplotlib, the goal is to design, implement, and compare these filters to clean noisy signals.

Structure:-

 Introduce theory behind FIR and IIR filters.

 Design filters using Python libraries.

 Generate noisy test signals.

 Apply filters and visualize results.

 Compare filter performance.

2.Fundamentals of Digital Filters

Discrete-Time Signals:-

Signals processed in digital systems are discrete in time, sampled at a sampling frequency fs. The Nyquist frequency fN=fs/2defines the maximum frequency representable without aliasing.

Digital Filters Overview:-

Filters process discrete samples to modify frequency components:

 Lowpass filters allow frequencies below cutoff fc.  Highpass filters allow frequencies above fc.

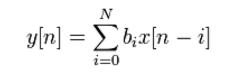
 Bandpass filters allow frequencies between two cutoffs.  Bandstop filters attenuate frequencies between two cutoffs.

Impulse Response and System Function:-

A filter’s impulse response defines how it responds to a single impulse. The system function H(z) characterizes filter behavior in the z-domain.

3. FIR Filters: Theory

FIR Filter Definition

An FIR filter has a finite number of coefficients bk: 

where N is the order of the filter.

Characteristics:-

 Non-recursive: output depends only on input.  Always stable.

 Can have exactly linear phase.

 Typically higher order needed for sharp transitions.

Design Using Window Method:-

The ideal lowpass filter impulse response is truncated using a window function (e.g., Hamming window) to limit length and reduce sidelobes.

4: IIR Filters: Theory

IIR Filter Definition:-

An IIR filter uses both inputs and previous outputs: 

Characteristics:-

 Recursive filter; output feedback.

 Can achieve sharper cutoff with fewer coefficients.  Stability depends on pole locations.

 Phase response is typically nonlinear.

Butterworth Filter:-

A Butterworth filter is maximally flat in the passband and has monotonic magnitude response, commonly used for general purpose lowpass filtering.

5: Problem Statement and Objectives

Problem Statement

Noisy signals complicate analysis and reduce system performance. The goal is to remove noise effectively without distorting signal features.

Objectives

 Generate noisy test signals with known frequencies.  Design FIR and IIR lowpass filters using Python.  Apply filters to noisy signals.

 Plot signals and filter frequency responses.

 Compare filter performance.

6: Software and Libraries

Python 3.x:-

The project is implemented in Python for its extensive scientific ecosystem.

Libraries:-

 NumPy: Efficient numerical computations and array handling.

 SciPy.signal: Signal processing functions including filter design and application.

 Matplotlib: Visualization of time series and frequency responses.

Installation:-

pip install numpy scipy matplotlib

7: Signal Generation and Noise Model

Clean Signal:-

We create a clean sine wave:

x(t)= sin(2πft)

with frequency f=5Hz.

Noise Model:-

Additive Gaussian noise and sinusoidal interference at 50 Hz are added

where noise is white Gaussian noise.

8: FIR Filter Design in Python Design Parameters:-

 Filter order

 Cutoff frequency fc=10 Hz.

 Sampling frequency fs=500 Hz.

Design Code:-

from scipy.signal import firwin

nyq = 0.5 \* fs

normalized\_cutoff = cutoff / nyq

fir\_coeff = firwin(numtaps=order+1, cutoff=normalized\_cutoff,

pass\_zero='lowpass')

Explanation:-

 numtaps is filter length = order + 1.

 pass\_zero='lowpass' designs a lowpass filter.

9: IIR Filter Design in Python

Butterworth Design:-

from scipy.signal import butter

b, a = butter(N=order,

Wn=normalized\_cutoff, btype='low')

 N is filter order.

 Wn is normalized cutoff.

 btype='low' for lowpass.

10: Applying Filters

FIR Filtering:-

from scipy.signal import lfilter

filtered\_fir = lfilter(fir\_coeff, 1.0, noisy\_signal)

IIR Filtering:-

Use zero-phase filtering to avoid phase distortion: from scipy.signal import filtfilt

filtered\_iir = filtfilt(b, a, noisy\_signal)

11: Frequency Response

FIR Filter:-

from scipy.signal import freqz

w, h = freqz(fir\_coeff)

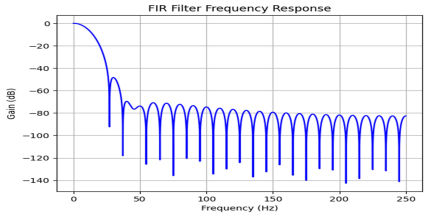
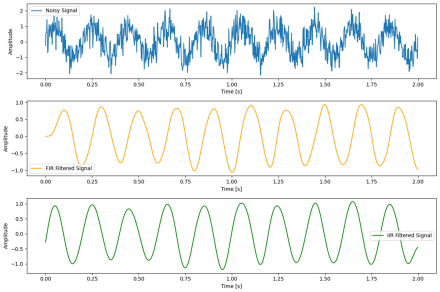
plt.plot(w \* fs / (2\*np.pi), 20 \* np.log10(abs(h)))

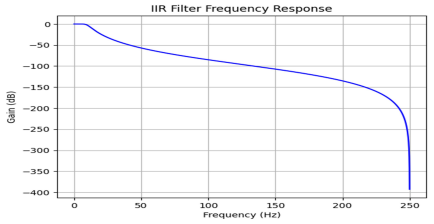
IIR Filter:-

Same method with numerator and denominator coefficients.

12: Visualization of Signals

noisy signal,FIR filtered and IIR filtered signals in time domain to visually assess noise reduction.





13: Performance Comparison Goal:-

Effectively suppress undesired components such as high frequency noise (e.g., 50 Hz interference) while preserving the desired signal (5 Hz sine wave).

FIR Filter:

 Strengths: Offers strong attenuation of frequencies above the cutoff, especially with higher filter orders.

 Observed Performance: The FIR filter successfully removed high-frequency noise, showing a smooth waveform in the filtered signal.

 Limitation: Requires a higher order to achieve a sharp cutoff, especially for narrow transition bands.

IIR Filter:

 Strengths: Achieves sharp roll-off near the cutoff frequency with relatively lower order.

 Observed Performance: The IIR filter effectively eliminated the 50 Hz interference with fewer coefficients.  Trade-off: More susceptible to ripple or gain irregularities near the cutoff band.

Verdict: Both filters attenuate noise well; IIR does it more efficiently (lower order), but FIR does so more predictably.

14: Applications

Filtering is vital in:-

 Audio denoising.

 Biomedical signal cleanup (ECG, EEG).

 Communications.

 Sensor data processing.

15: Extending the Project Ideas include:

 Designing bandpass and highpass filters.  Adaptive filtering techniques.

 Real-time filtering.

 Multirate filtering.

16: Challenges

 Choosing filter parameters.

 Managing phase distortion.

 Balancing order vs complexity.

 Noise modeling accuracy.

17: Full Python Code Listing

import numpy as np

import matplotlib.pyplot as plt

from scipy.signal import firwin, lfilter, freqz, butter, filtfilt

def design\_fir\_filter(order, cutoff, fs, filter\_type='low'):

nyq = 0.5 \* fs

normalized\_cutoff = np.array(cutoff) / nyq

if filter\_type == 'low':

pass\_zero = True

elif filter\_type == 'high':

pass\_zero = False

elif filter\_type in ['bandpass', 'bandstop']:

pass\_zero = filter\_type

else:

raise ValueError("Invalid filter\_type. Choose from 'low', 'high', 'bandpass', 'bandstop'.")

fir\_coeff = firwin(order + 1, normalized\_cutoff, pass\_zero=pass\_zero) return fir\_coeff

def design\_iir\_filter(order, cutoff, fs, filter\_type='low'):

nyq = 0.5 \* fs

normalized\_cutoff = np.array(cutoff) / nyq

b, a = butter(order, normalized\_cutoff, btype=filter\_type, analog=False) return b, a

def apply\_filter(b, a, signal, use\_filtfilt=False):

if use\_filtfilt:

filtered\_signal = filtfilt(b, a, signal) # zero-phase filtering

else:

filtered\_signal = lfilter(b, a, signal)

return filtered\_signal

def plot\_frequency\_response(b, a=1, fs=1.0, title='Frequency Response'): w, h = freqz(b, a, worN=8000)

plt.plot((fs \* 0.5 / np.pi) \* w, 20 \* np.log10(abs(h)), 'b') plt.title(title)

plt.xlabel('Frequency (Hz)')

plt.ylabel('Gain (dB)')

plt.grid(True)

plt.show()

if \_\_name\_\_ == "\_\_main\_\_":

fs = 500.0 # Sampling frequency (Hz)

t = np.arange(0, 2.0, 1/fs) # Time vector for 2 seconds

# Create a noisy signal: 5 Hz sine + white noise + 50 Hz interference freq\_signal = 5.0

noisy\_signal = (

np.sin(2 \* np.pi \* freq\_signal \* t) +

0.5 \* np.random.randn(len(t)) +

0.3 \* np.sin(2 \* np.pi \* 50 \* t)

)

# Filter parameters

fir\_order = 50

iir\_order = 4

cutoff = 10 # cutoff frequency (Hz)

filter\_type = 'low' # lowpass filter

# Design FIR filter

fir\_b = design\_fir\_filter(fir\_order, cutoff, fs, filter\_type) # Design IIR filter

iir\_b, iir\_a = design\_iir\_filter(iir\_order, cutoff, fs, filter\_type)

# Apply filters

fir\_filtered = lfilter(fir\_b, [1.0], noisy\_signal)

iir\_filtered = apply\_filter(iir\_b, iir\_a, noisy\_signal, use\_filtfilt=True)

# Plot time domain signals

plt.figure(figsize=(12, 8))

plt.subplot(3, 1, 1)

plt.plot(t, noisy\_signal, label='Noisy Signal')

plt.legend()

plt.xlabel('Time [s]')

plt.ylabel('Amplitude')

plt.subplot(3, 1, 2)

plt.plot(t, fir\_filtered, label='FIR Filtered Signal', color='orange') plt.legend()

plt.xlabel('Time [s]')

plt.ylabel('Amplitude')

plt.subplot(3, 1, 3)

plt.plot(t, iir\_filtered, label='IIR Filtered Signal', color='green') plt.legend()

plt.xlabel('Time [s]')

plt.ylabel('Amplitude')

plt.tight\_layout()

plt.show()

# Plot frequency responses

plot\_frequency\_response(fir\_b, fs=fs, title='FIR Filter Frequency Response') plot\_frequency\_response(iir\_b, iir\_a, fs=fs, title='IIR Filter Frequency Response'

18: Experimental Results

 Filter effectiveness.

 Frequency response plots.

 Signal waveforms.

19: Conclusions

Summary of findings: FIR filters provide stable linear phase response; IIR filters are efficient but phase nonlinear. Both can effectively clean noisy signals when properly designed.