REPORT

Zajęcia: Analog and digital electronic circuits

Teacher: prof. dr hab. Vasyl Martsenyuk

Lab 5 and 6

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Topic:

5. Digital Filter Design and Analysis: Implementing FIR and IIR filters in Python.

6. Adaptive Filtering: Applying adaptive filtering algorithms to noise reduction.ls

Variant 15

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Informatyka II stopień,
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1 semestr,
Gr. B

1. Problem statement:

The goal of this task is to design FIR, IIR and LMS filters in Python.

1. FIR filter with the following coefficients and implement it in Python to reduce noise in a noisy sinusoidal signal.
2. IIR filter with the following coefficients and implement it in Python to reduce noise in the same noisy sinusoidal signal.
3. Adaptive LMS filter in Python to reduce noise in the same noisy sinusoidal signal.

2. Input data:

1. FIR Filter Coefficients: b = {0.2, 0.3, 0.5}
2. IIR Filter Coefficients: b = {1, 0.5}, a = {1, −0.7}
3. LMS filter with a step size μ = 0.05 and filter length M = 6

3. Commands used (or GUI):

a) source code

```
import numpy as np
import matplotlib.pyplot as plt
```

```
fir_b = [ 0.2,  0.3, 0.5]

iir_b = [ 1.0,  0.5 ]
iir_a = [ 1.0, -0.7 ]

lms_mu = 0.05
lms_m = 6
```

```
fs = 1000  # Sampling frequency
t = np.linspace(0, 1, fs)

f = 36 # base signal
```

```python
signal_base = np.sin(2 * np.pi * f * t)
signal_harmonic_1 = np.sin(2 * np.pi * 2 * f * t) /2
signal_harmonic_2 = np.sin(2 * np.pi * 3 * f * t) /3

signal = signal_base + signal_harmonic_1 + signal_harmonic_2

noise = np.random.randn(len(t))/4

noisy_signal = signal + noise

plt.figure(figsize=(10, 6))
plt.plot(t, noisy_signal, ms=1, label= "Noisy Signal" )
plt.plot(t, signal, ms=3, label= "Pure Signal" )
plt.legend()
plt.title( "Signal" )
plt.xlabel( "Time [s]" )
plt.ylabel( "Amplitude" )
plt.grid()
plt.show()
```

```python
# $y[n] = \sum_{k=0}^M b_k x\[n - k\]$
def fir_filter(x, b):
    """
    FIR filter implementation.

    Parameters:
    x : ndarray
        Input signal.
    b : ndarray
        Filter coefficients.

    Returns:
    y : ndarray
        Filtered output signal.
    """
    M = len(b)  # Number of coefficients
    y = np.convolve(x, b, mode='full')[:len(x)]  # Apply
filter
    return y
```

```python
# $y[n] = \sum_{k=0}^M b_k x[n - k] - \sum_{k=1}^N a_k y[n -
k]$
def iir_filter(x, b, a):
    """
    FIR filter implementation.

    Parameters:
    x : ndarray
        Input signal.
    b : ndarray
        Filter coefficients.
    a : ndarray
        Denominator coefficients.

    Returns:
    y : ndarray
        Filtered output signal.
    """
    return lfilter(b, a, x)
```

```python
def lms_filter(x, d, mu, num_taps):
    """
    LMS adaptive filter implementation.

    Parameters:
    x : ndarray
        Input signal (noisy).
    d : ndarray
        Desired signal.
    mu : float
        Step size.
    num_taps : int
        Number of filter taps.

    Returns:
    y : ndarray
        Filtered output signal.
    e : ndarray
        Error signal.
    w : ndarray
        Final filter weights.
```

```python
    """
    n = len(x)
    w = np.zeros(num_taps)
    y = np.zeros(n)
    e = np.zeros(n)

    for i in range(num_taps, n):
        x_segment = x[i-num_taps:i][::-1]
        y[i] = np.dot(w, x_segment)
        e[i] = d[i] - y[i]
        w += mu * e[i] * x_segment

    return y, e, w

fir_filtered = fir_filter(noisy_signal,fir_b)
iir_filtered = iir_filter(noisy_signal, iir_b, iir_a)
lms_filtered, e, w = lms_filter(noisy_signal, signal, lms_mu,
lms_m)
```

```python
plt.figure(figsize=(15, 10))

plt.subplot(5, 1, 1)
plt.plot(t, noisy_signal, label='Noisy Signal')
plt.title("Noisy Signal")
plt.grid()
plt.legend()

plt.subplot(5, 1, 2)
plt.plot(t, fir_filtered, label='FIR Filtered', color='g')
plt.title("FIR Filter Output")
plt.grid()
plt.legend()

plt.subplot(5, 1, 3)
plt.plot(t, iir_filtered, label='IIR Filtered', color='r')
plt.title("IIR Filter Output")
plt.grid()
plt.legend()

plt.subplot(5, 1, 4)
plt.plot(t, lms_filtered, label='LMS Filtered', color='m')
```

```
plt.title("LMS Filter Output")
plt.grid()
plt.legend()

plt.subplot(5, 1, 5)
plt.plot(t, signal, label='Signal', color='b')
plt.title("Original signal")
plt.grid()
plt.legend()

plt.tight_layout()
plt.show()
```

```
# All results at once
plt.figure(figsize=(15, 5))

plt.plot(signal / max(signal), ms=3, label='Original',
color='b')
plt.plot(noisy_signal / max(noisy_signal), ms=3, label='with
noise')
plt.plot(fir_filtered / max(fir_filtered), ms=3, label='FIR',
color='g')
plt.plot(iir_filtered / max(iir_filtered), ms=3, label='IIR',
color='r')
plt.plot(lms_filtered / max(lms_filtered), ms=3, label='LMS',
color='m')
plt.xlabel('$time$')
plt.ylabel('$Amplitude$')
plt.xlim(360,730)
plt.legend()
plt.grid()
```

```
# All results compared to original
plt.figure(figsize=(15, 10))

plt.subplot(4, 1, 1)
plt.plot(signal / max(signal), ms=3, label='Original',
color='b')
plt.plot(noisy_signal / max(noisy_signal), ms=3, label='with
noise')
```

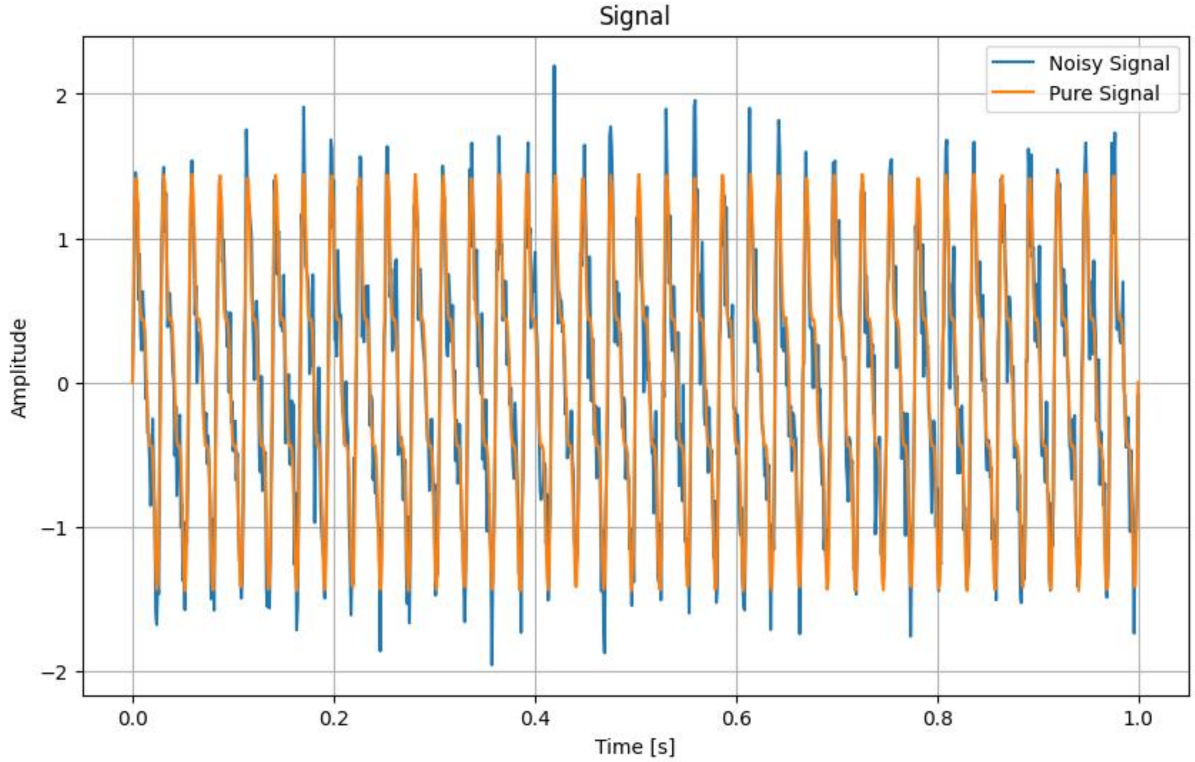
```python
plt.plot(fir_filtered / max(fir_filtered), ms=3, label='FIR',
color='g')
plt.plot(iir_filtered / max(iir_filtered), ms=3, label='IIR',
color='r')
plt.plot(lms_filtered / max(lms_filtered), ms=3, label='LMS',
color='m')
plt.xlabel('$time$')
plt.ylabel('$Amplitude$')
plt.xlim(0,370)
plt.legend()
plt.grid()

plt.subplot(4, 1, 2)
plt.plot(signal / max(signal), ms=3, label='Original',
color='b')
plt.plot(fir_filtered / max(fir_filtered), ms=3, label='FIR',
color='g')
plt.xlabel('$time$')
plt.ylabel('$Amplitude$')
plt.xlim(0,370)
plt.legend()
plt.grid()

plt.subplot(4, 1, 3)
plt.plot(signal / max(signal), ms=3, label='Original',
color='b')
plt.plot(iir_filtered / max(iir_filtered), ms=3, label='IIR',
color='r')
plt.xlabel('$time$')
plt.ylabel('$Amplitude$')
plt.xlim(0,370)
plt.legend()
plt.grid()

plt.subplot(4, 1, 4)
plt.plot(signal / max(signal), ms=3, label='Original',
color='b')
plt.plot(lms_filtered / max(lms_filtered), ms=3, label='LMS',
color='m')
plt.xlabel('$time$')
plt.ylabel('$Amplitude$')
```

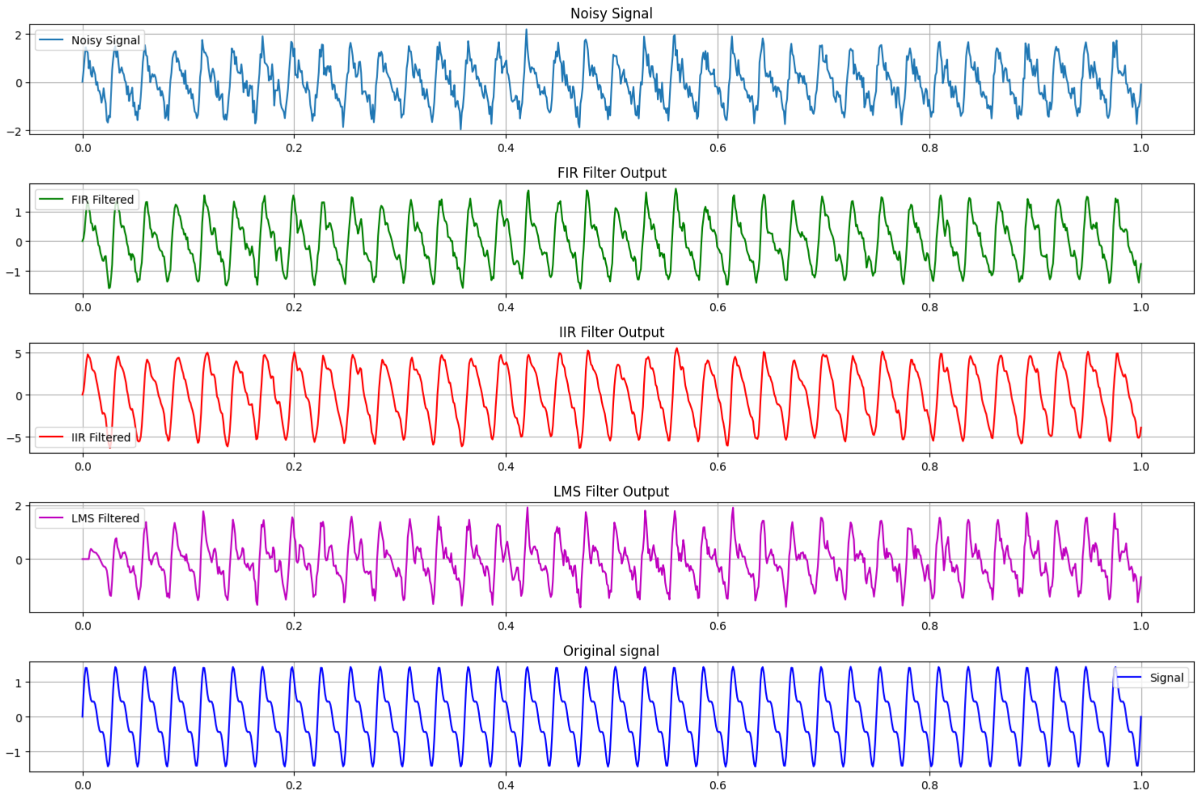
```
plt.xlim(0,370)
plt.legend()
plt.grid()

plt.show()
```

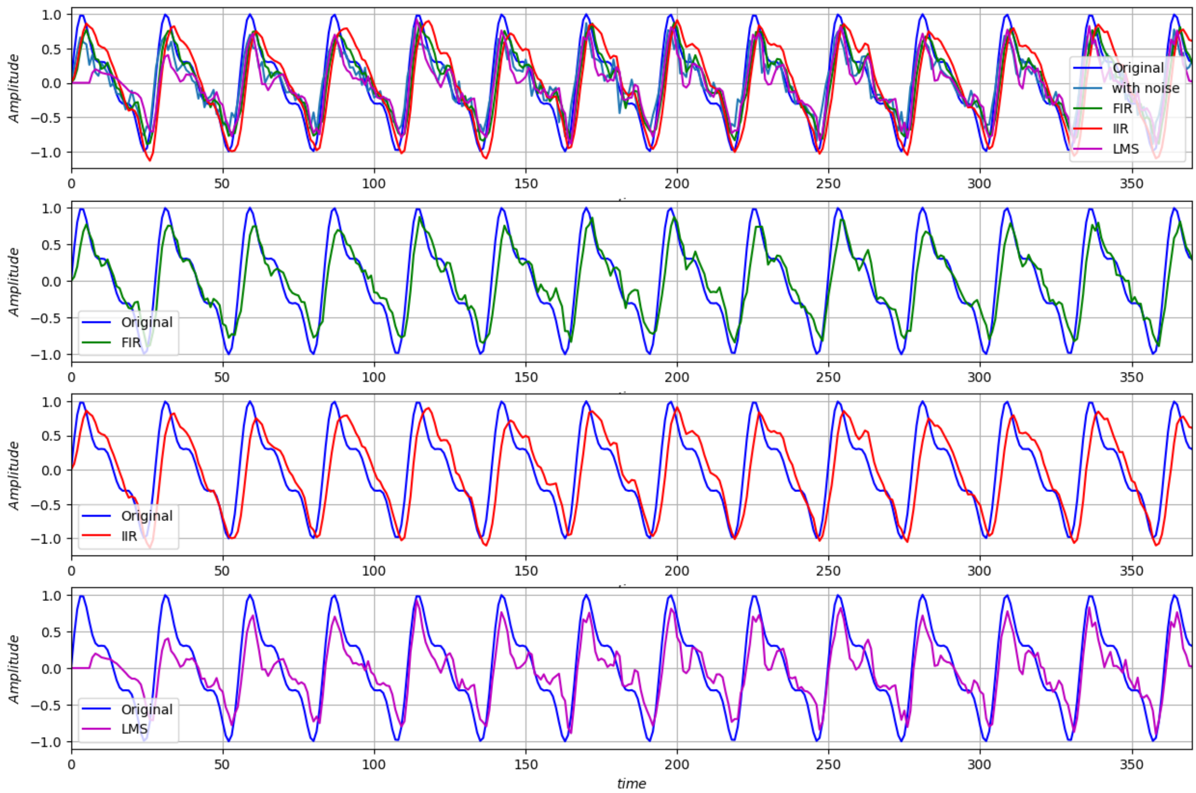
b) Link to remote repositorium

https://github.com/TobiaszWojnar/DSP

4. Outcomes:




Noisy Signal
Noisy Signal
FIR Filter Output
FIR Filtered
IIR Filter Output
IIR Filtered
LMS Filter Output
LMS Filtered
Original signal
Signal


Amplitude
Original
with noise
FIR
IIR
LMS
Original
FIR
Original
IIR
Original
LMS
time

5. Conclusions

FIR filters

In general FIR filters excel at noise reduction without altering the signal's phase, a critical advantage in phase-sensitive applications. However, their performance hinges on coefficient selection and may necessitate higher filter orders for sharp frequency cutoffs.

For my signal filtered signal seemed to be shifted in phase a bit, but it was managed to to capture higher frequency signals

IIR filters

In general IIR filters, offer superior frequency selectivity with fewer coefficients but introduce phase distortion and require careful design to guarantee stability, especially at higher orders.

For my singal it also shifted phase and higher frequencies where porly captured

LMS adaptive filters

LMS adaptive filters dynamically adjust to changing noise characteristics, making them suitable for dynamic environments, though their effectiveness depends on the step size and filter length. This comparison underscores the need to carefully consider the trade-offs between these filter types to optimize digital signal processing performance.

For my singal it precisely captured fraquency and phase of the signal but seems to be trying to overemphasis aditinonal frequencies.