Indian Institute of Technology Jodhpur
EEL2010: Signals and Systems
Programming Assignment

Submitted By:
Atharva Pandey [B20CS007]
Divyam Patel [B20EE082]

PROBLEM STATEMENT:

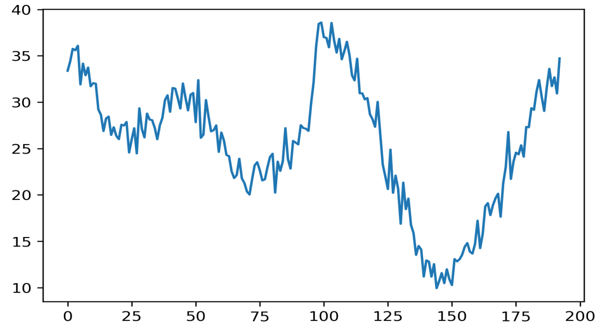
One of the many applications of the Internet of Things (IoT) consists of continuous monitoring of temperature in an area. To that end, several temperature sensors are installed at different locations. These sensors measure and store the recorded value of temperature over time. However, due to the limitations of hardware, the sensor memory needs to be cleared periodically and this is done by transmitting the stored values to a base unit. Assume that x[n] denotes the samples of the true temperature value recorded by a sensor. However, it is found that the received signal y[n] at the base unit suffers from blur distortions and noise (additive). Hence, the signal y[n] needs to be first processed so that we can recover x[n] from it. Assume that blur happens via a system characterized by an impulse response h[n] = 1/16 [1 4 6 4 1] (assume that the center value of 6/16 corresponds to n = 0). Then, implement the following two approaches to recover the original signal x[n] from distorted signal y[n]:
1. First, remove noise and then sharpen (deblur). Let the resulting signal be x1[n].
2. First sharpen (deblur) and then remove noise. Let the resulting signal be x2[n].
Now, compare x1[n] and x2[n] with x[n]. What conclusions can you draw from your observations? Also, explain your observations from a theoretical perspective if possible.

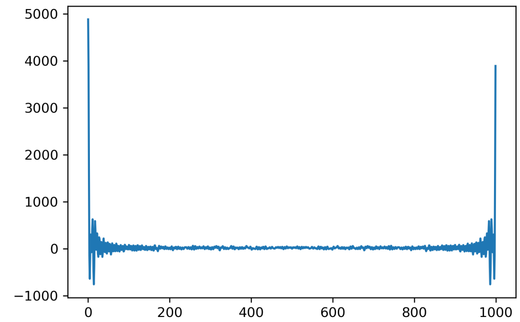
APPROACH:

To recover the original signal x[n] from y[n], the following 2 approaches are used -

1) First remove the noise (Denoise) and then deblur to recover the original signal.
2) First deblur the distorted signal and remove the noise (Denoise) to recover the original signal.

Analysis of Input Signal -





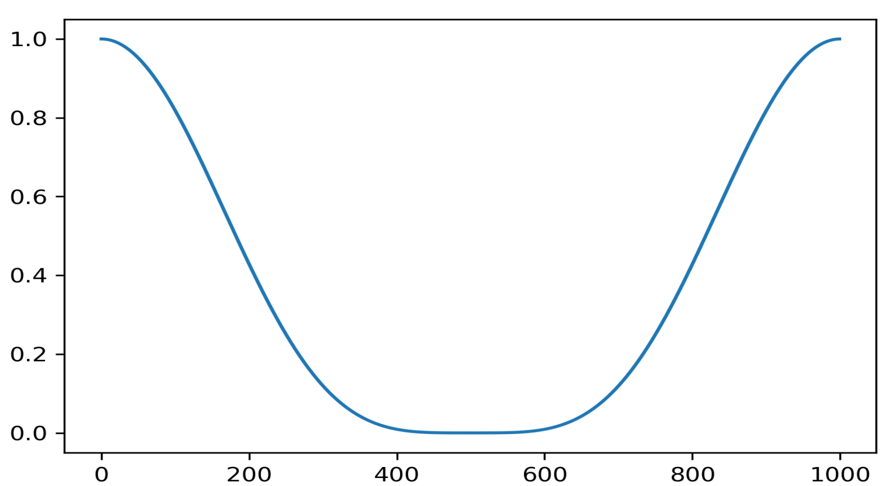
Input Signal ***Fourier Transform of Input Signal***

We can see that the input signal comprises two significant peaks in its Fourier transform, one of lower frequency and the other of higher frequency, and the Fourier transform is also composed of other frequencies but in lower amplitudes. Hence, they would have lower contributions. So, if we can preserve the two peaks in its Fourier transform, we could retrieve the majority of the signal. This shows us the possibility that a band-reject filter rejects the frequencies which are lower in amplitude between the two impulses.

Deblurring System -

Given a blurring system, it convolves the input signal with the inverse of the blurring system and provides the deblurred signal as the output.

Working:



Fourier Transform of the given Blurring System

The above-given plot represents the Fourier transform of the Blurring system in the given problem statement. We can see that the Fourier transform approaches zero at the frequency of Pi (2Pi/1000 * 500). Hence, the inverse system would have an impulse at this point. To take care of the situations when the Fourier transform of the blurring system tends to zero, a threshold is introduced close to zero.

Denoising Systems -

- Averaging Filter: It replaces the value of the signal at a point with the average of the value of the signal at neighboring points. For boundary cases, Padding is applied.

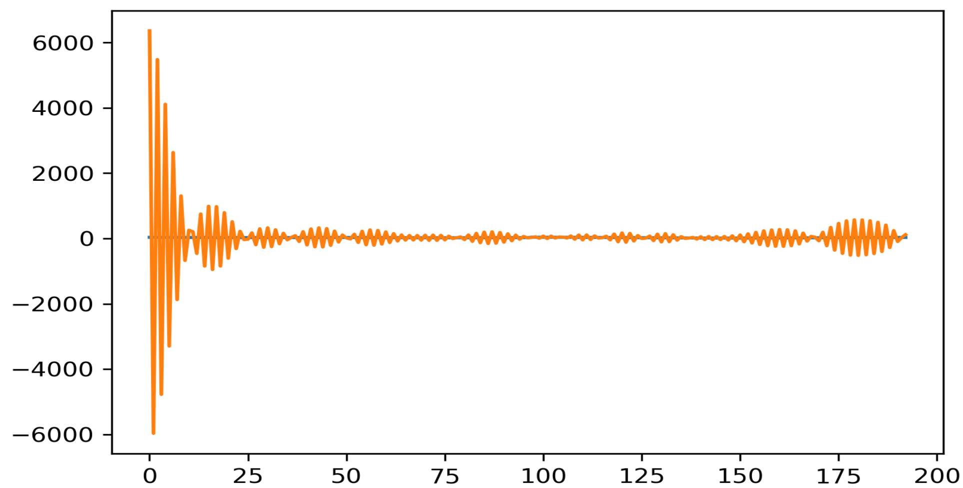
- Low Pass Filter: A filter that passes signals with a frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency

- Amplitude Based Suppression: It suppresses the frequencies whose amplitude in the signal's Fourier transform is less than the threshold frequency.

RESULT / THEORETICAL EXPLANATION:

A) Using Average Filter -

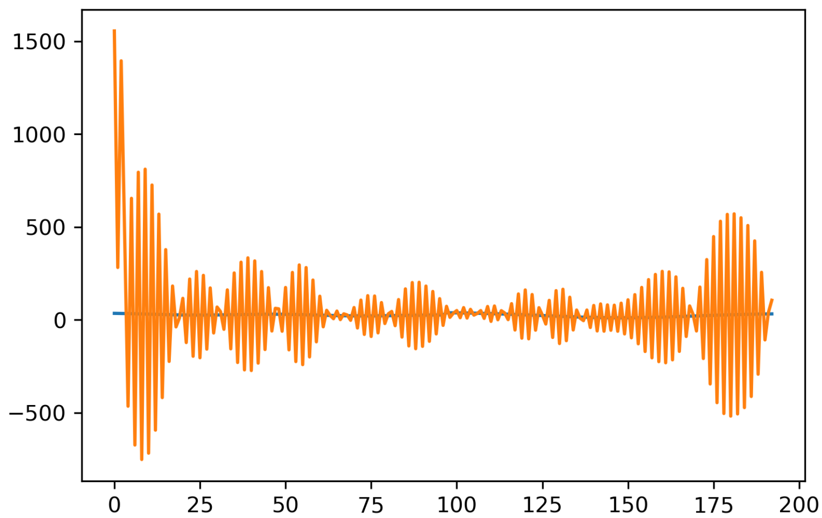
a) Task 1



First the signal is filtered and then deblurred. The filter replaces the value of the signal at a point with the average of the value of the signal at 10 neighboring points. For boundary cases, zero padding is applied. The deblurring system takes the denoised signal, divides it Fourier transform with Fourier transform of the blurring system and applies inverse Fourier to retrieve the output signal. The output signal is compared with the input signal and the ***RMSE value*** found is ***972.39***

The above-shown result does not resemble the targeted input value due to ineffective denoising. Since averaging is unable to remove the noise efficiently, thus the deblurring system causes the noise to be amplified and this results in the above signal plot which doesn't resemble the original signal.

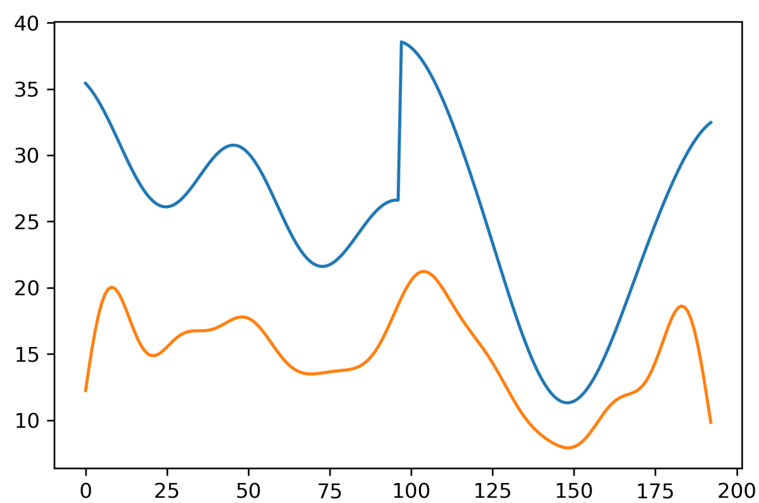
b) Task 2



Deblurring causes the noise to amplify and the signal becomes unusable. Now denoising is of no use. The output signal is compared with the input signal and the ***RMSE value*** found is ***289.23***

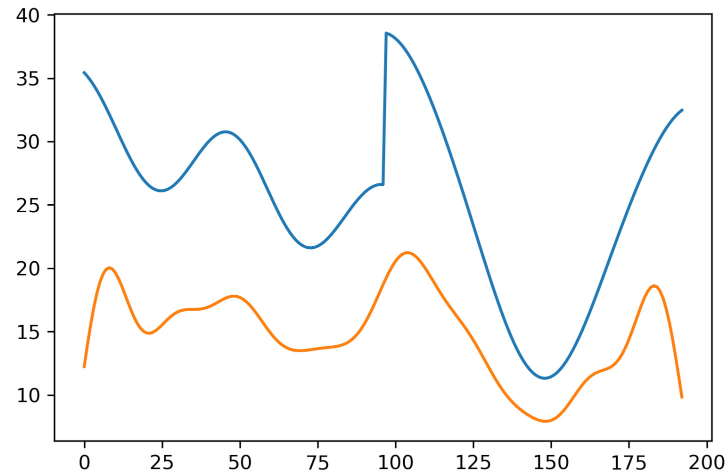
B) Using Low Pass Filter -

a) Task 1



First the Fourier transform of the input signal is found and it is passed through Low Pass Filter and then deblurred. Since a low pass filter only allows frequencies lower than the cutoff frequency to pass through it causes the loss of higher frequencies that are a part of the signal. Hence a major component of energy of the signal is lost and which is seen in the above plot where the output signal (orange graph) is very less when compared to the expected output signal (blue graph). The output signal is compared with the input signal and the ***RMSE value*** found is ***11.18***

b) Task 2

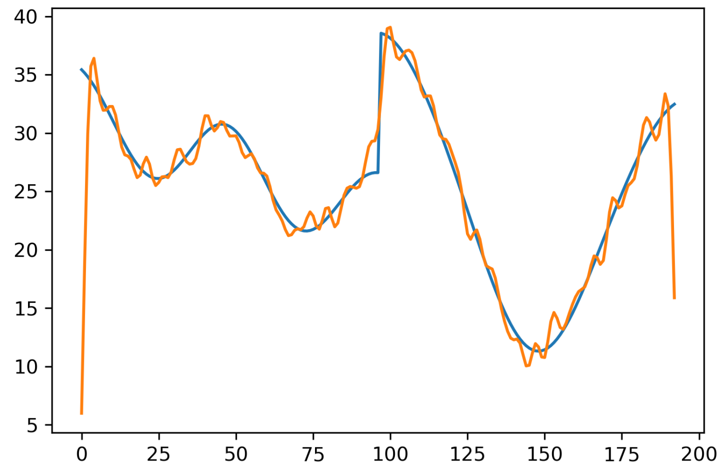


First the input signal is deblurred and then it is passed through a low pass filter. The input signal on deblurring has a high component of frequencies that make up noise. However, these frequencies are greater than the cutoff frequency of the low pass filter and hence are removed. Also, the high-frequency component of the input signal is lost. Thus the output signal (orange plot) is similar to that of Task 1, with less energy and smaller than the expected output (blue plot). The output signal is compared with the input signal and the ***RMSE value*** found is ***11.18***

C) Amplitude Based Filter -

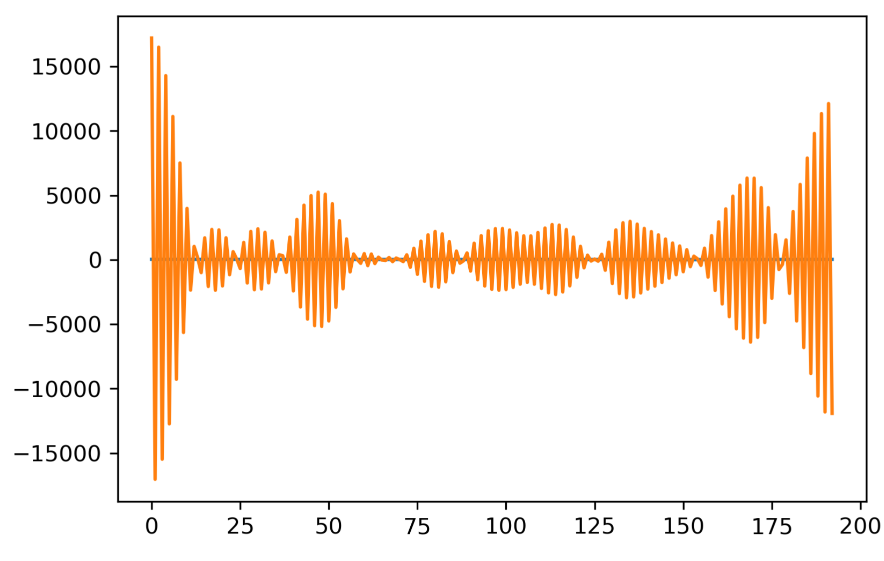
Since the noise is a higher frequency component of a signal but with less amplitude in its Fourier transform (i.e., it does not contribute significantly to the signal). So, we designed an Amplitude-based filter that would remove the frequency components less than a particular threshold amplitude.

a) Task 1



First the input signal is passed through an amplitude-based filter for denoising and then deblurred. The amplitude-based filter removes the frequencies that have a low contribution to the input signal. The denoised signal was then passed through the deblurring system to get the output signal. In the above figure, the output signal (orange plot) and the expected output signal (blue plot) are shown. It can be seen that the output closely resembles the expected output signal. The output signal is compared with the input signal and the ***RMSE value*** found is ***2.94***

b) Task 2



The input signal is first passed through a deblurring system and then through an amplitude-based filter in order to get the output signal. The deblurring system causes the amplification of the frequencies constituting noise which renders the amplitude-based filtering moot. The above plot shows a comparison of the output signal (orange plot) and the expected output signal (blue plot). The expected output signal is not visible since the noise has been amplified. The output signal is compared with the input signal and the ***RMSE value*** found is ***4486.07***

CONCLUSION:

RMSE VALUES

	TASK 1	**TASK 2**
Average Filter	972.39	289.23
Low Pass Filter	11.18	11.18
Amplitude Based Filter	2.94	4486.07

Deblurring is common in all the experiments. Denoising filters were varied.
For various denoising filters, we can conclude:

- In Average Filtering: the RMSE value suggests that this method is not suitable for either task and hence for processing the given input signal.
- In Low Pass Filtering: the RMSE value suggests that this method is not suitable for either task since it removes the higher frequency components of the signal. Hence, it is not useful for processing the given input signal.
- In Amplitude Based Filtering: the RMSE value suggests that this method is suitable for Task 1 (deblurring after denoising) however in Task 2 (denoising after deblurring) noise is amplified.

Other Findings:

- Cascading the average filter and Amplitude Based filtering improves the RMSE values and gives a more approximate output signal.
- A bandpass filter would have been useful in both tasks. However, it would have only worked for the above-given input signal and could not be implemented for processing a different signal from the temperature sensor.