Audio Filtering

EE23BTECH11013 - Avyaaz*

Parameter	Description
$x(n)$	Input audio signal
$y(n)$	Output audio signal
$H(e^{j\omega})$	Discret Time Fourier Transform of $x(n)$
$h(n)$	Impulse response

TABLE 1: Parameters

I. Spectrogram

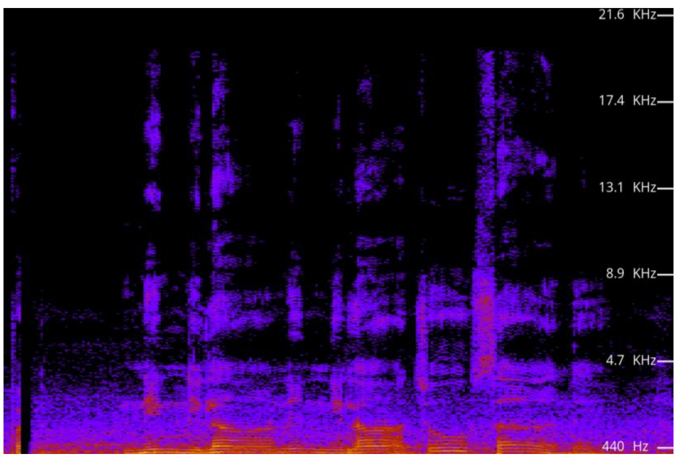

Fig. 1: Spectrogram of input audio

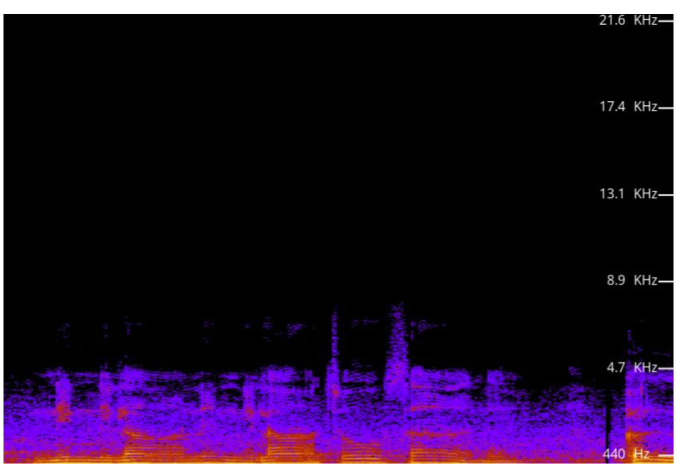

Fig. 2: Spectrogram of output audio

The key strokes as well as background noise is subdued in the audio.

II. Digital Filter Input - Output

$x(n)$ typically represents the input signal at discrete time indices n.

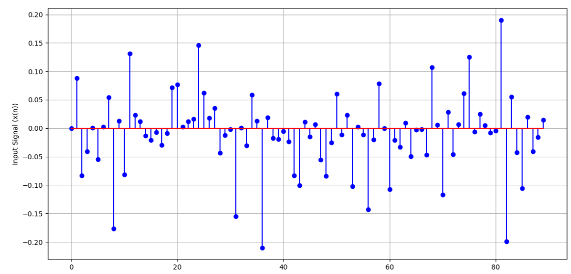

Fig. 3: Plot of $x(n)$ vs n

Relationship between input and audio signal can be obtained from the difference equation:

$$\sum_{m=0}^{M} a(m)\, y(n-m) = \sum_{k=0}^{N} b(k)\, x(n-k) \tag{1}$$

where, coefficients of a and b are obtained from the 'noise_reduction.py'

$$a = [1, -2, 1, 0] \tag{2}$$

$$b = [0.01, 0.05, 0.05, 0.01] \tag{3}$$

$$\begin{aligned} y_{fwd}[n] &= b[0]*x[n]+b[1]*x[n-1]+b[2]*x[n-2] \\ &+ b[3]*x[n-3] - a[1]*y_{fwd}[n-1] \\ &- a[2]*y_{fwd}[n-2] - a[3]*y_{fwd}[n-3] \end{aligned} \tag{4}$$

$$\begin{aligned} y_{bwd}[n] &= b[0]*y_{fwd}[n]+b[1]*y_{fwd}[n-1]+b[2]*y_{fwd}[n-2] \\ &+ b[3]*y_{fwd}[n-3] - a[1]*y_{bwd}[n+1] \\ &- a[2]*y_{bwd}[n+2] - a[3]*y_{bwd}[n+3] \end{aligned} \tag{5}$$

$$y[n] = \frac{y_{fwd} + y_{bwd}}{2} \tag{6}$$

The forward and backward filtering operations are used in the implementation of the 'filtfilt' function to achieve zero-phase filtering.

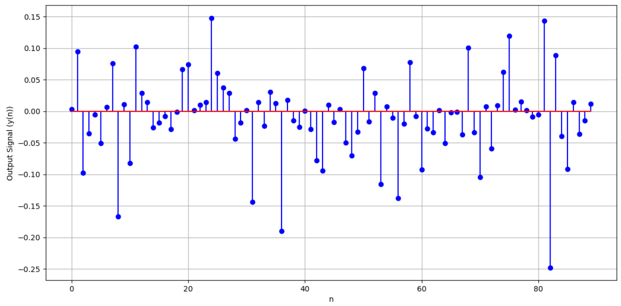

Fig. 4: Plot of $y(n)$ vs n

III. Frequency Response

We know that,

$$\mathcal{Z}\{x(n-k)\} = z^{-k}X(z) \tag{7}$$

From (6): Assuming that the Z-transform is a linear operation.

$$H(z) = \frac{Y(z)}{X(z)} \tag{8}$$

$$H(z) = \frac{0.01z^{-3} + 0.05z^{-2} + 0.05z^{-1} + 0.01}{z^{-3} - 2z^{-2} + z^{-1}} \quad ; |z| \neq 1, 0 \tag{9}$$

Using,

$$H\left(e^{j\omega}\right) = H\left(z = e^{j\omega}\right) \tag{10}$$

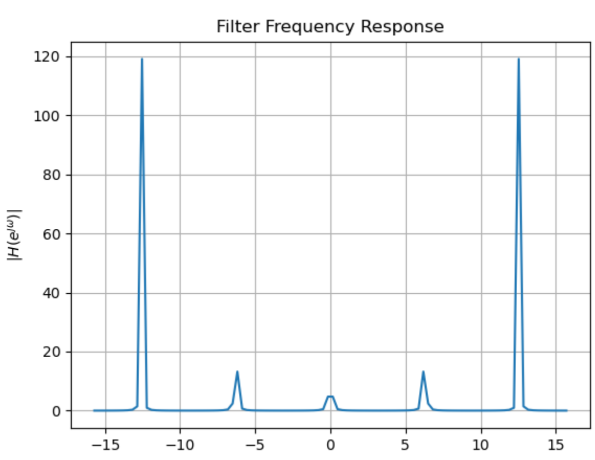

Fig. 5: Plot of $|H(e^{j\omega})|$ vs ω

IV. Impulse Response

From equation (9):

$$H(z) = 1 - \frac{1}{z^{-1}} \tag{11}$$

Taking inverse of $H(z)$:

$$H(z) \overset{\mathcal{Z}^{-1}}{\longleftrightarrow} h(n) \tag{12}$$

$$h(n) = \delta(n) - \delta(n+1) \tag{13}$$

where,

$$\delta(n) = \begin{cases} 1 & n = 0 \\ 0 & \text{otherwise} \end{cases} \tag{14}$$

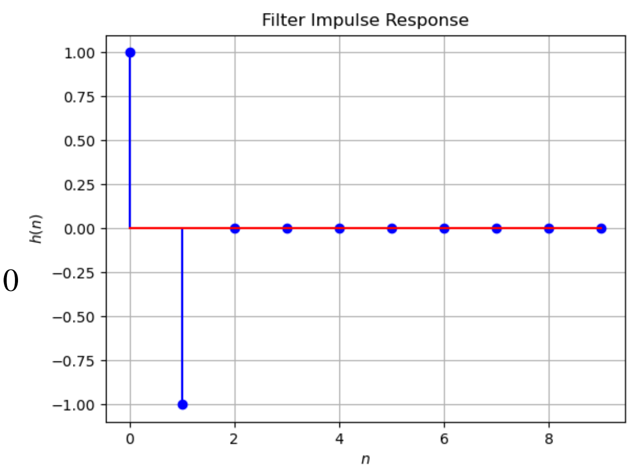

Fig. 6: Plot of $h(n)$ vs n