भारतीय प्रौद्योगिकी संस्थान तिरुपति

TIRUPATI

DIGITAL SIGNAL PROCESSING

MINI PROJECT REPORT

Spectrogram and Periodogram Analysis

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1.ABSTRACT :

The spectrogram is a useful tool for analysing time and frequency of signals simultaneously. The plot looks like a graph of the energy content of a signal expressed as function of frequency and time. Graph of a signal in which the vertical axis is frequency, the horizontal axis is time, and amplitude is shown as a colormap. As it provides data in both the time and frequency domain, provide a means of easily discerning important details about an event it becomes much easier for analysis. So in this report we are trying to create a 3D model of the spectrogram of a signal rather than simply looking it in 2D flat image. We will also visualise how the data will be plotted in MATLAB. This report also includes a section on the theoretical basis for the technique, with relevant time-frequency distributions, and a section on plot interpretation strategies. Further, several practical examples of field application are brought forth to demonstrate its usefulness. In conclusion we will also site some areas where it is implemented and has scope in certain area of interest. In signal processing, a ***periodogram*** *is an estimate of the spectral density of a signal. The term was coined by Arthur Schuster in 1898.[1] Today, the periodogram is a component of more sophisticated methods (see spectral estimation). It is the most common tool for examining the amplitude vs frequency characteristics of FIR filters and window functions. FFT spectrum analysers are also implemented as a time-sequence of periodograms.*

KeyWords:

Fast Fourier Transformation (FFT) .

2.INTRODUCTION:

Spectrogram :

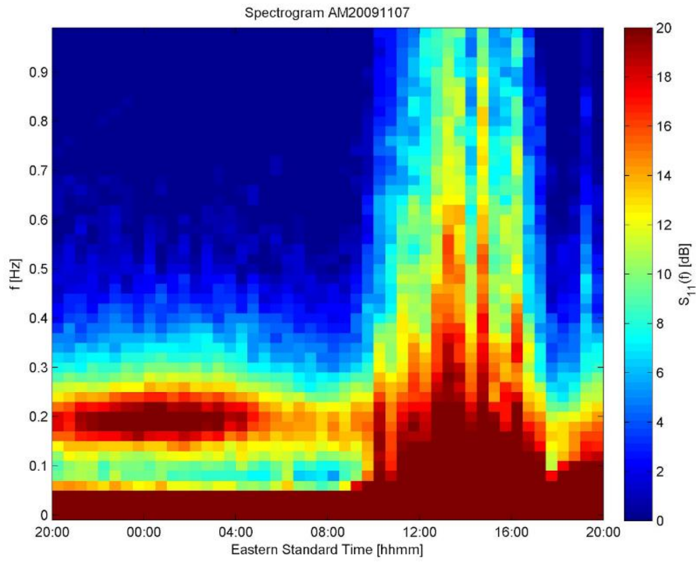
What do we mean by a spectrogram of a signal?

- A spectrogram is a visual way of representing the signal strength, or “loudness”, of a signal over time at various frequencies present in a particular waveform.

- Not only can one see whether there is more or less energy at, for example, 2 Hz vs 10 Hz, but one can also see how energy levels vary over time.

- In other sciences spectrograms are commonly used to display frequencies of sound waves produced by humans, machinery, animals, whales, jets, etc., as recorded by microphones.

- In the seismic world, spectrograms are increasingly being used to look atrize different types of earthquakes or other vibrations in the earth frequency content of continuous signals recorded by individual or groups of seismometers to help distinguish and characterize different types of earthquakes or other vibrations in the earth



How to generate a spectrogram?

- Creating a spectrogram using the FFT is a digital process.

- Digitally sampled data, in the time domain, is broken up into chunks, which usually overlap, and Fourier transformed to calculate the magnitude of the frequency spectrum for each chunk.

- Each chunk then corresponds to a vertical line in the image; a measurement of magnitude versus frequency for a specific moment in time (the midpoint of the chunk).

- These spectrums or time plots are then "laid side by side" to form the image or a three-dimensional surface, or slightly overlapped in various ways, i.e. windowing.

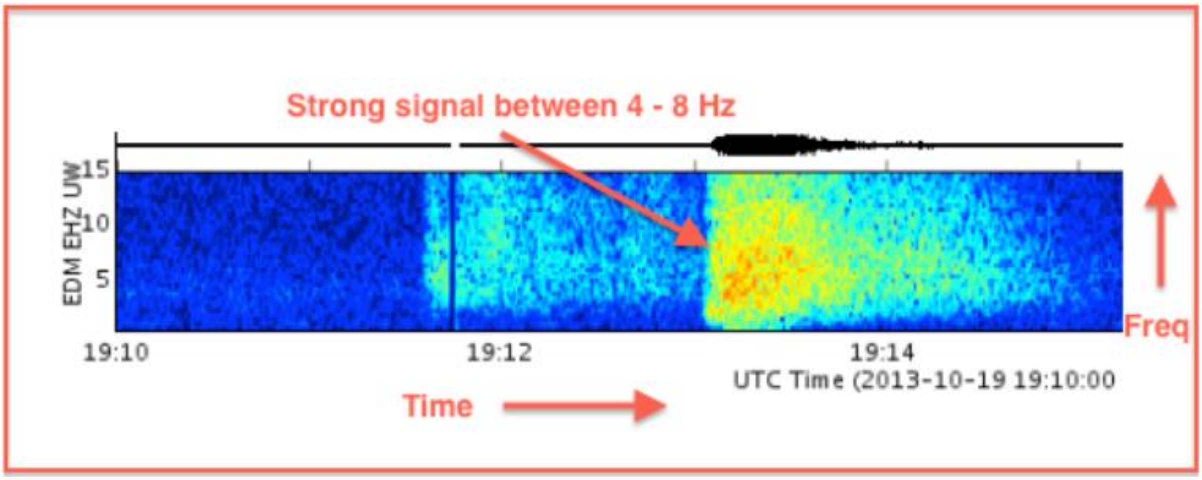
- This process essentially corresponds to computing the squared magnitude of the short-time Fourier transform (STFT) of the signal

How to read a spectrogram?

- Spectrograms are basically two-dimensional graphs, with a third dimension represented by colors. Time runs from left (oldest) to right (youngest) along the horizontal axis.

- The vertical axis represents frequency, which can also be thought of as pitch or tone, with the lowest frequencies at the bottom and the highest frequencies at the top.

- The amplitude (or energy or “loudness”) of a particular frequency at a particular time is represented by the third dimension, color, with dark blues corresponding to low amplitudes and brighter colors up through red corresponding to progressively stronger (or louder) amplitudes



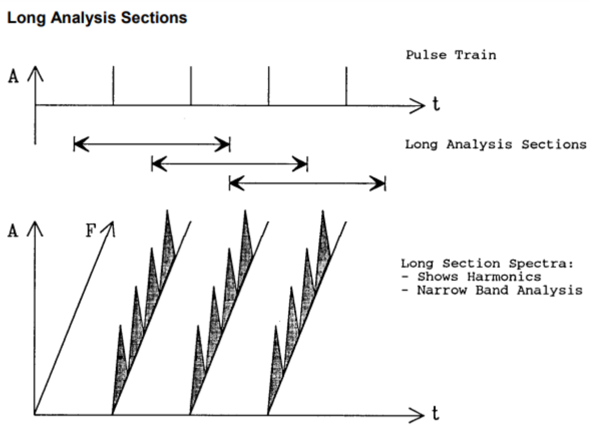
A spectrogram is a representation of how the frequency content of a signal changes with time. Time is displayed along the x-axis, frequency along the y-axis, and the amount of energy in the signal at any given time and frequency is displayed as a level of grey. During regions of silence, and at frequency regions where there is little energy, the spectrogram appears blue ; yellow regions indicate areas of high energy – caused for example by vocal fold closures, harmonics, or formant vibration in a speech signal. We use two types of spectrogram for speech study: one which emphasises the frequency aspects by using long signal sections or narrow analysis filters, and one which emphasises the temporal aspects by using short signal sections or wide analysis filters. Narrow-band spectrograms are convenient for investigating characteristics of the source: they show the harmonics of the vocal fold vibration for example. Wide-band spectrograms are convenient for investigating characteristics of the vocal tract filter: they highlight the vocal tract resonances (formants) by showing how they continue to vibrate after a vocal fold pulse has passed through.

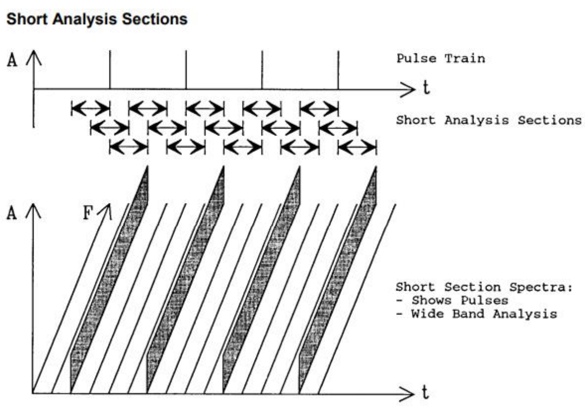
Wide Band Spectrogram :

A spectrogram produced using an analysis scheme which emphasises temporal changes in the signal: with short-time spectrum calculations (about 3ms) or highly damped analysis filters (about 300Hz).

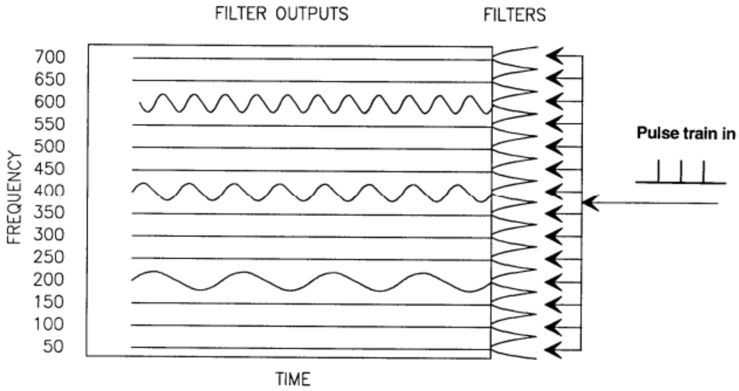
Narrow-band spectrogram:

A spectrogram produced using an analysis scheme which emphasises frequency changes in the signal: with long-time spectrum calculations (about 20ms) or lightly damped analysis filters (about 45Hz).

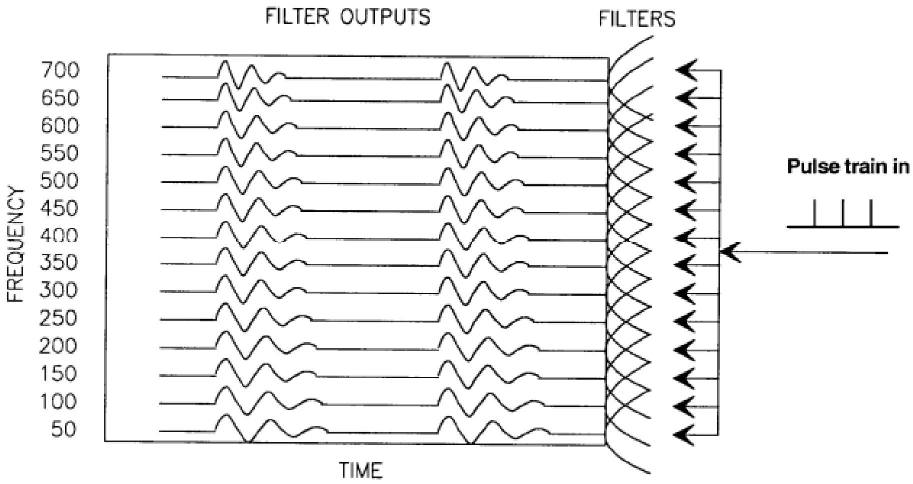


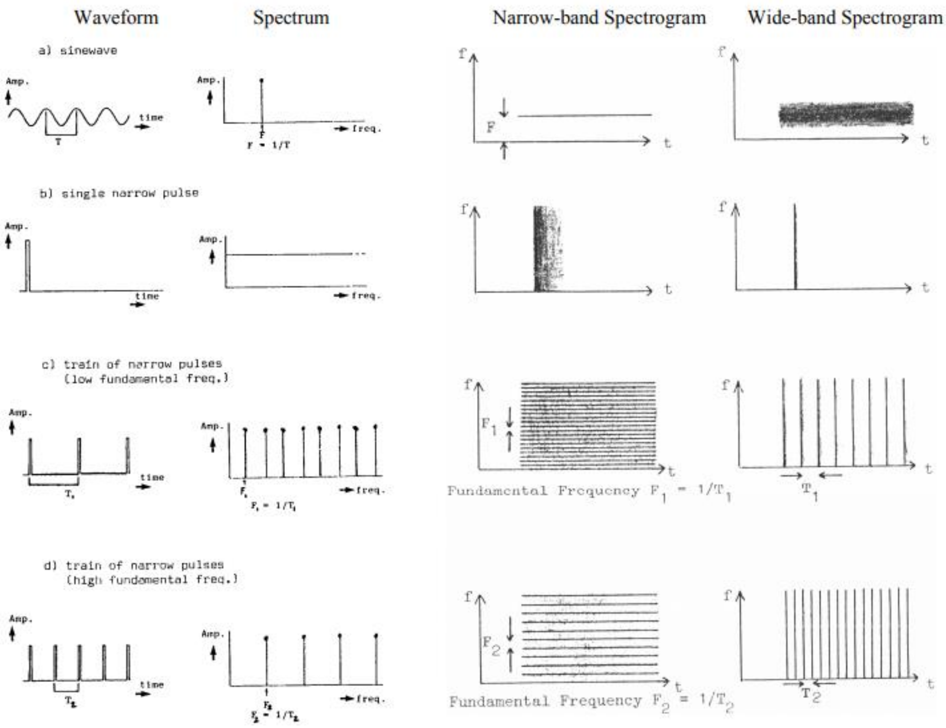


Narrow Analysis Filters



Wide Analysis Filters





So to explain the difference in simple term between wide band spectrogram and narrow band spectrogram , is that if we are more concerned about the frequency then we need to choose the narrow band frequency so that we will get the exact value of frequency but that will be carried for long time so we will get less precision in the time is lost . so if we consider the wide band spectrogram then we will be having more control over the time than the frequency so the frequency would be having less precision , so we should take an optimum value so that both will be managed .

To plot the spectrogram we just need to follow these simple steps, first slicing the given signal into chunks and then we will apply the FFT for each chunk and then just place all of then side by side .

Now coming to the

Periodogram of a signal:

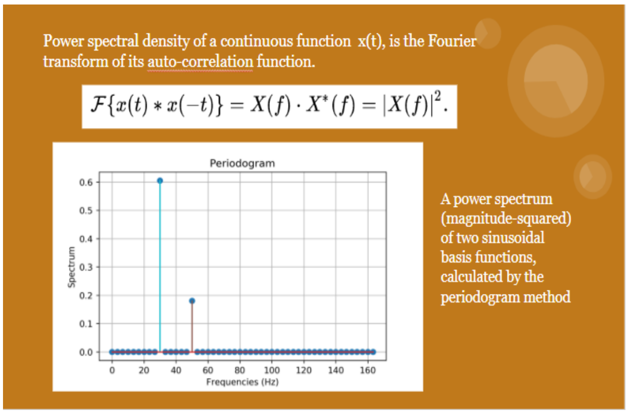
What do we mean by periodogram of a signal?

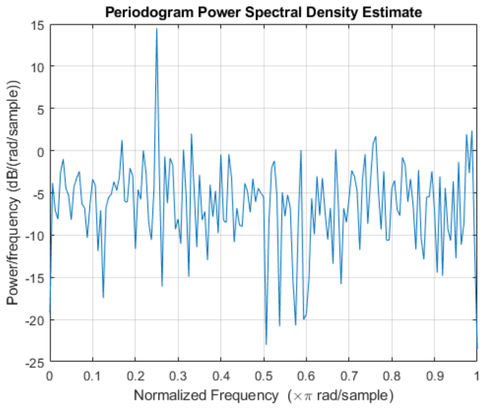
- In signal processing, a periodogram is an estimate of the spectral density of a signal.

- The power spectrum of a time series x(t) describes the distribution of power into frequency components composing that signal.

- According to Fourier analysis, any physical signal can be decomposed into a number of discrete frequencies, or a spectrum of frequencies over a continuous range.

- The statistical average of a certain signal or sort of signal (including noise) as analyzed in terms of its frequency content, is called its spectrum.





Main Application: It is the most common tool for examining the amplitude vs frequency characteristics of FIR filters and window functions

There is nothing much to tell about periodogram even for the Periodogram we have considered it definition which is that it is the power spectral density of the continuous or discrete signal in our case it is the discrete signal., is the Fourier transformation of its auto- correlation function

$$\mathcal{F}\{x(t) * x(-t)\} = X(f) \cdot X^*(f) = |X(f)|^2$$

3. LITERATURE SURVEY:

Environmental Sound Recognition using spectrogram image feature -
https://www.academia.edu/40500768/ENVIRONMENTAL_SOUND_RECOGNITION_US

ING_SPECTROGRAM_IMAGE_FEATURES

A_Comparative_Modeling_and_Analysis_of_Voltage_Variation_by_Using_Spectrogram- https://www.academia.edu/38903231/A_Comparative_Modeling_and_Analysis_of_Voltage_Variation_by_Using_Spectrogram

Comparison between the performance of spectrogram and multiwindow spectrogram in digital modulation communication signals. - https://ieeexplore.ieee.org/document/4448613/

Acoustic Event Classification Using Spectrogram Features - https://ieeexplore.ieee.org/document/8650444/

4.METHOD:

Spectrogram:

We basically just took the definition and worked on it as it is just a time and

.

frequency signal plotted simultaneously , spectrogram was nothing but a , we first break the signal into chunks and then we apply windowed FFT(Fast Fourier Transformation) for each chunk of the signal with some overlap with the previous chunk and usually we take the over lap of 50% with the previous chunk (or window) and then plot the absolute (magnitude) along the column wise , and then we place all the those columns side by side and there you go we have obtained our spectrogram .

Periodogram:

So what we did was we just calculated the FFT of the x[n] function which is nothing but X(*f*), because while plotting the FFT of the signal we usually take the modulus and then plot it , and as we will also plot the logarithmic value of the result obtained so its just we need to multiply the result by 2 to get the actual periodogram

ALGORITHM OVERVIEW

Spectrogram:

```
function y =  Spectrogram_finalcode(filename)
    [x,~] = audioread(filename);
    x = x(:,1);
    winlen = 500;
    overlap = winlen/2;
    num = [winlen : overlap :length(x)];
    SPECTROGRAM_PLOT = zeros(  winlen/2, length(num) );
    for i=1:length(num)
        framed = x((num(i)-winlen) + 1 : num(i) );
        dft = fft(framed);
        SPECTROGRAM_PLOT(:,i) = 20*log(abs(dft(1:winlen/2)));
    end

    figure()
    subplot(1,2,1)
    surf((SPECTROGRAM_PLOT))
    colorbar
    shading interp
    view(0,90)
    title('Spectrogram of ' + filename + ' file by our code :')
    xlabel('Time \rightarrow');
    ylabel('Frequency \rightarrow');
    subplot(1,2,2)
    spectrogram(x,'yaxis',winlen)
    title('Spectrogram of ' + filename + ' file by inbuilt code :')
end
```

Step 1: We will read the audio file.

Step 2: Choose some window length (in the code we too it to be 500 samples)

Step 3: Now choose the amount of overlap required (in our case we have taken it to be 50%)

Step 4: Now create a matrix of the size of window length / 2 (rows) and number of chunks we broke the signal into (in our case it's the 2 times (length of the signal / window length)-1)

Step 5:Now we will run a for loop for evaluating the FFT of the each chunk at a time and then assign them to the matrix which we have created.

Step 6: And that's it we have to now plot the matrix.

Periodogram:

```
function y =  Periodogram_finalcode(filename)
[x,~]=audioread(filename);
x = x(:,1);
f = fft(x);
f = f(1:floor(length(x)/2));
figure()
subplot(2,1,1)
plot(linspace(0,1,floor(length(x)/2)),10*log(abs(f)))
grid on;
title('Periodogram Power Spectral Density Estimate (OUR Code)for the file : ' + filename )
xlabel('Normalized Frequency (x \pi rad/sample)');
ylabel('Power/frequency (dB/rad/sample)');
subplot(2,1,2)
periodogram(x);
end
```

Steps 1: Plotting the periodogram is way much simpler than spectrogram, first we need to read the audio file.

Steps 2: Now we need to compute the FFT of the signal.

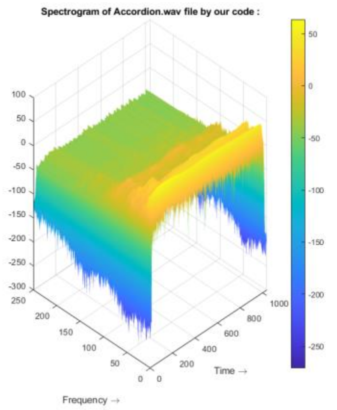
Steps 3: As the FFT will give us complex values so we need to plot the magnitude of the complex value.

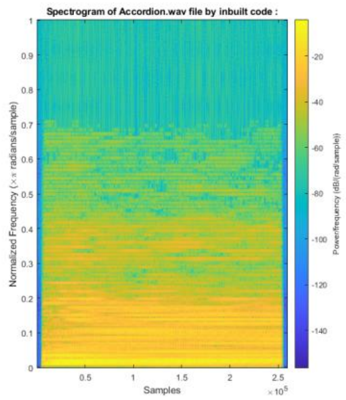
Steps 4: As we know that periodogram is the power spectral density of the signal , also while plotting we will plot the log of the values so as we are suppose to evaluate the autocorrelation and then apply the FFT but ultimately it will result the square of magnitude of X(*f*) , when we plot the log of the value which will be 2 times log of the magnitude of X(*f*).

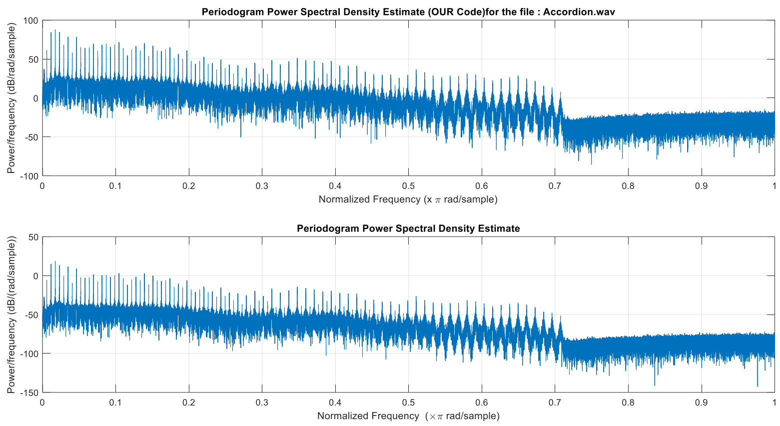
5. EXPERIMENTAL RESULTS:

We have plotted some of the spectrogram and periodogram of some musical instruments.:

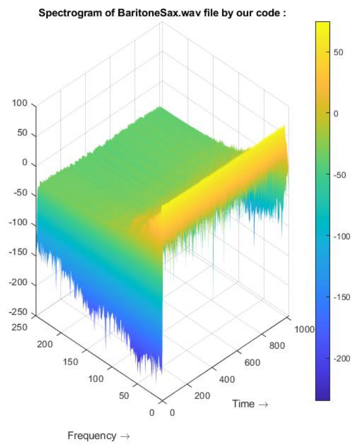
Accordion:

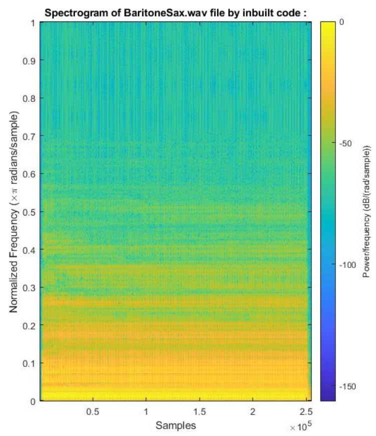


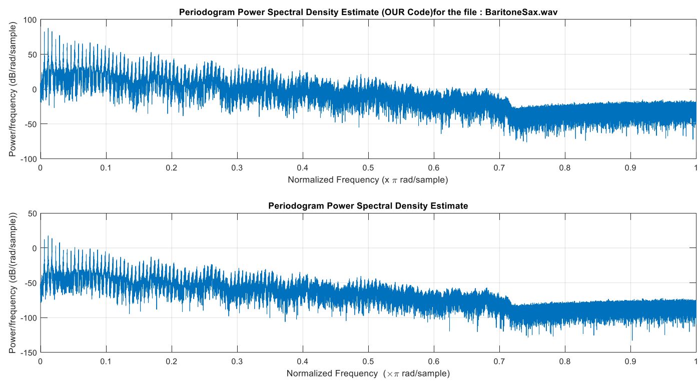




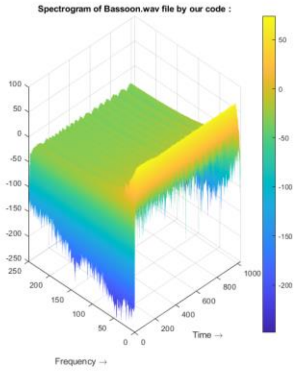
Baritone Sax

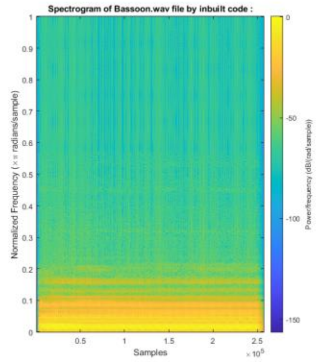


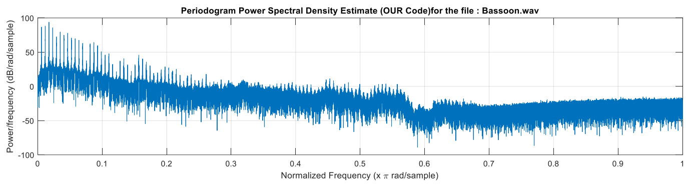


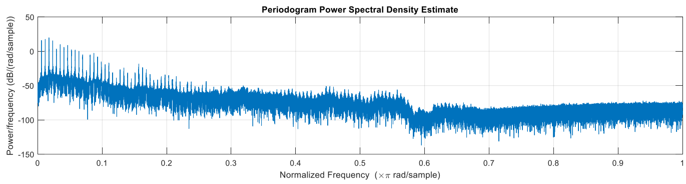


Bassoon

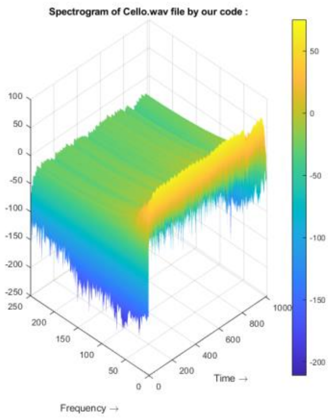


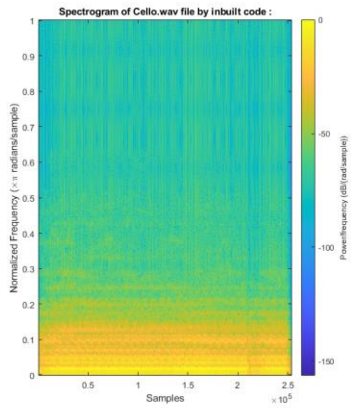


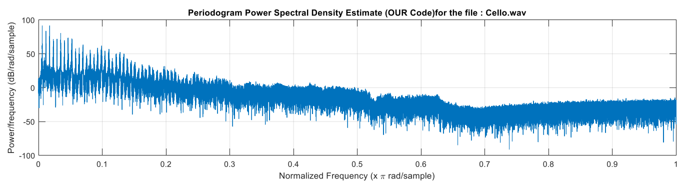


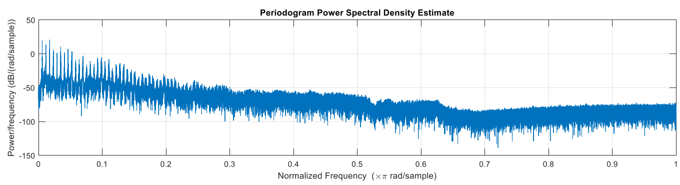


Cello

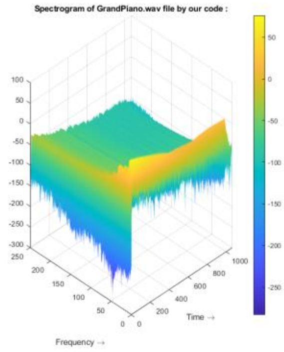


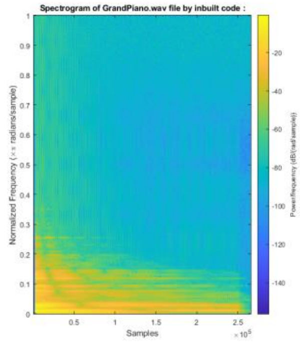


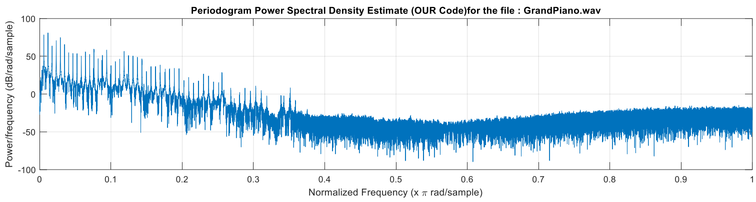


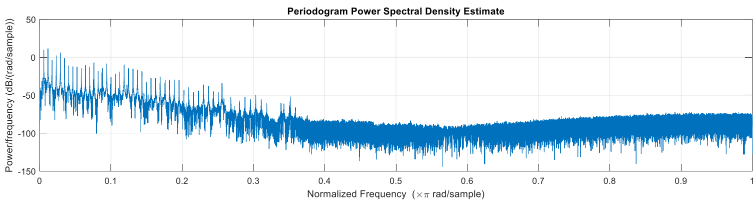


GrandPiano

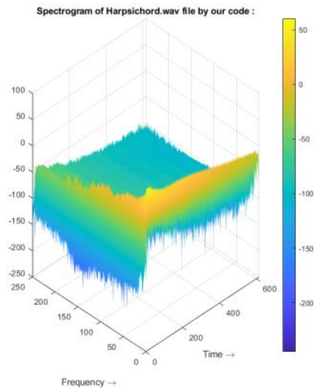


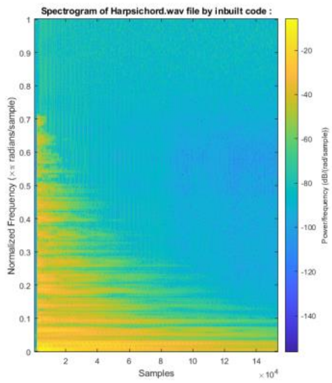


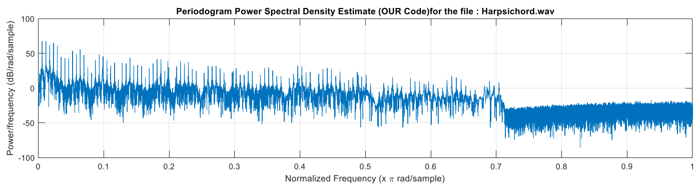


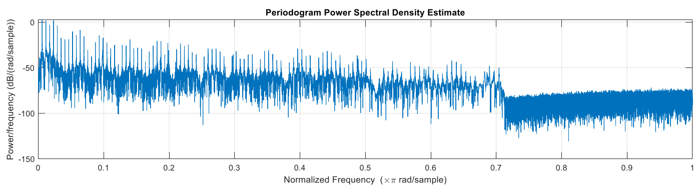


Harpsichord

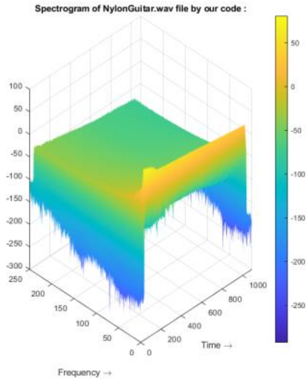


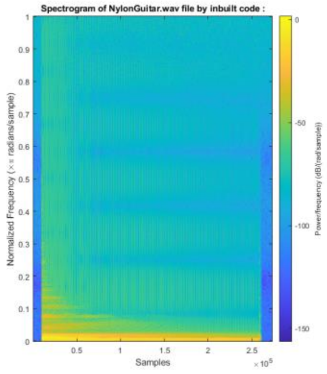


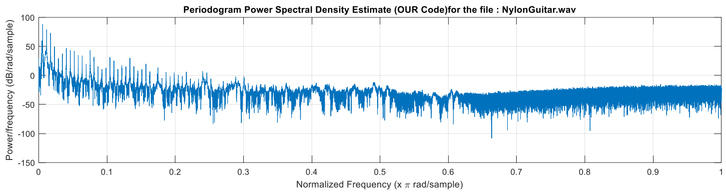


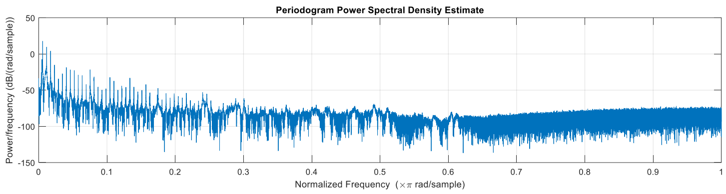


Nylon Guitar

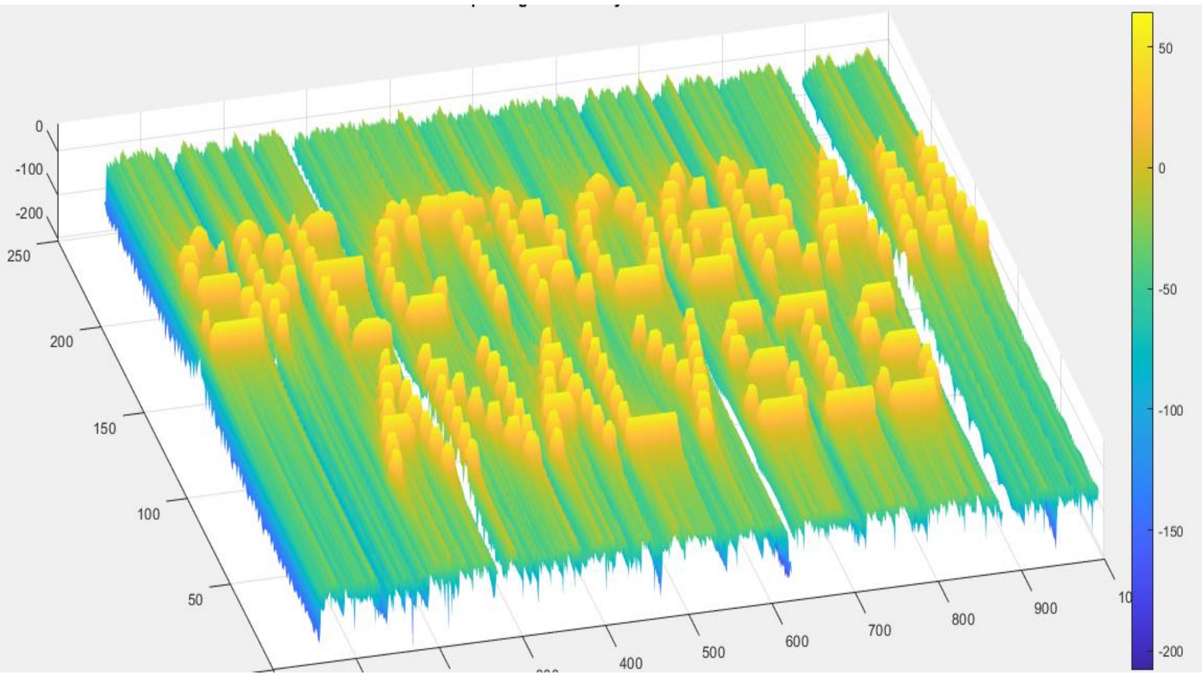






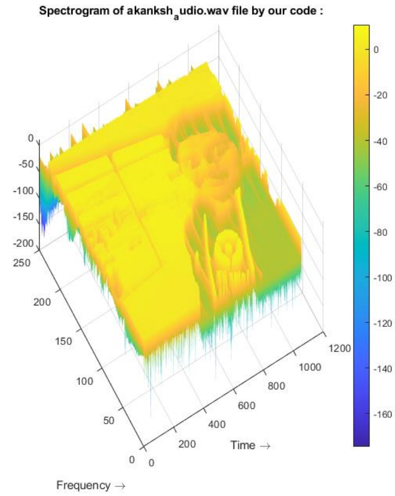


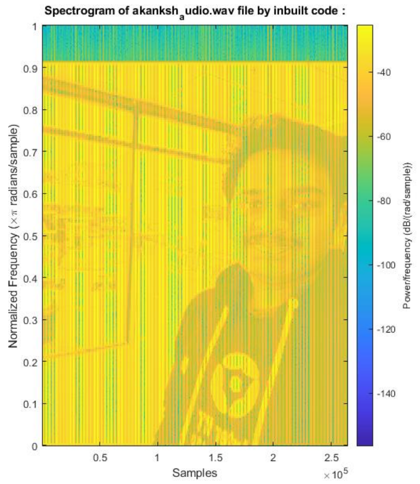
NOW THIS IS SOMETHING SPECIAL , WE HAVE GOT A WORDS IN THE SPECTROGRAM!!

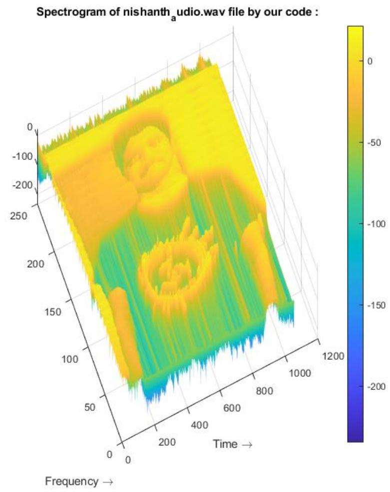


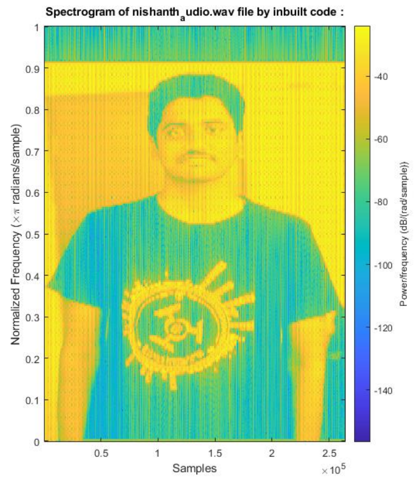
YOU MIGHT BE THINKING THAT IF IT IS POSSIBLE TO GET **A WORD** ON THE **SPECTROGRAM**, WHETHER A **PHOTO** CAN BE OBTAINS ? AND THE ANSWER IS **YES!**

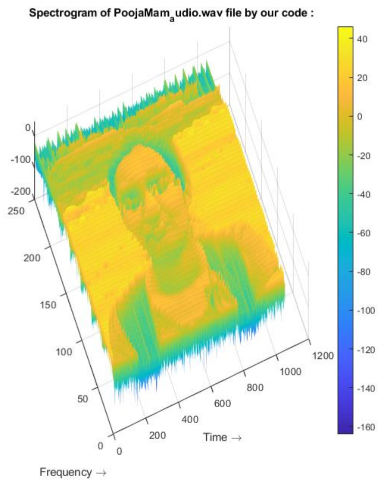
Here are some of the photos which we tried to plot it on the spectrogram :

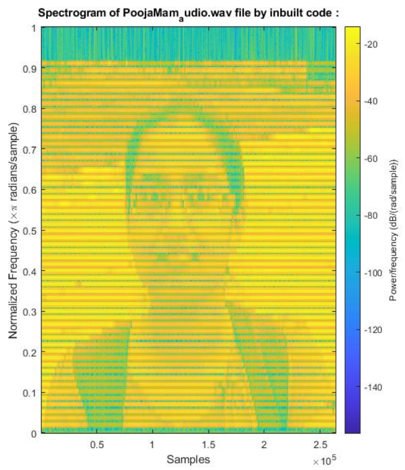












I GUESS THIS IS THE INTERESTING PART OF OUR PROJECT !

Where we tried to encrypt an image in to an audio file and if we play the audio file we won't understand anything because there will be only some frequency playing randomly which won't make any sense , but if we try to plot the spectrogram then we will get the actual information hidden in it (So we have succesfully converted a 2d image into id signal!!!!)

6.APPLICATIONS:

Spectrogram :

- Early analog spectrograms were applied to a wide range of areas including the study of bird calls (such as that of the great tit), with current research continuing using modern digital equipment[8] and applied to all animal sounds. Contemporary use of the digital spectrogram is especially useful for studying frequency modulation (FM) in animal calls. Specifically, the distinguishing characteristics of FM chirps, broadband clicks, and social harmonizing are most easily visualized with the spectrogram.
- Spectrograms are useful in assisting in overcoming speech deficits and in speech training for the portion of the population that is profoundly deaf
- The studies of phonetics and speech synthesis are often facilitated through the use of spectrograms.
- In deep learning-based speech synthesis, spectrogram (or spectrogram in mel scale) is first predicted by a seq2seq model, then the spectrogram is fed to a neural vocoder to derive the synthesized raw waveform.
- By reversing the process of producing a spectrogram, it is possible to create a signal whose spectrogram is an arbitrary image. This technique can be used to hide a picture in a piece of audio and has been employed by several electronic music artists. See also steganography.
- Some modern music is created using spectrograms as an intermediate medium; changing the intensity of different frequencies over time, or even creating new ones, by drawing them and then inverse transforming. See Audio timescale-pitch modification and Phase vocoder.
- Spectrograms can be used to analyse the results of passing a test signal through a signal processor such as a filter in order to check its performance.
- High definition spectrograms are used in the development of RF and microwave systems
- Spectrograms are now used to display scattering parameters measured with vector network analysers
- The US Geological Survey and the IRIS Consortium provide near real-time spectrogram displays for monitoring seismic stations
- Spectrograms can be used with recurrent neural networks for speech recognition.

Periodogram :

When a periodogram is used to examine the detailed characteristics of an FIR filter or window function, the parameter N is chosen to be several multiples of the non-zero duration of the $x[n]$ sequence, which is called zero padding. When it is used to implement a filter bank, N is several sub-multiples of the non-zero duration of the $x[n]$ sequence .

One of the periodogram's deficiencies is that the variance at a given frequency does not decrease as the number of samples used in the computation increases. It does not provide the averaging needed to analyse noise like signals or even sinusoids at low signal-to-noise ratios. Window functions and filter impulse responses are noiseless, but many other signals require more sophisticated methods of spectral estimation. Two of the alternatives use periodograms as part of the process:

- The method of averaged periodograms,[more commonly known as Welch's method, divides a long x[n] sequence into multiple shorter, and possibly overlapping, subsequences. It computes a windowed periodogram of each one, and computes an array average, i.e. an array where each element is an average of the corresponding elements of all the periodograms. For stationary processes, this reduces the noise variance of each element by approximately a factor equal to the reciprocal of the number of periodograms.
- Smoothing is an averaging technique in frequency, instead of time. The smoothed periodogram is sometimes referred to as a spectral plot.

Periodogram-based techniques introduce small biases that are unacceptable in some applications. Other techniques that do not rely on periodograms are presented in the spectral density estimation article.

7.CONCLUSION:

So We have shown how viewing the time frequency domain can yield more useful information than the time frequency domains alone. .Data analysis using frequency time domain is advantageous for non-stationary signals – those that fluctuate over time.

There are may different time frequency distributions and the literature clearly describes the characteristic. However, we have found that simply using spectrogram (windowed FFT)help in most of the applications . The spectrogram is computationally efficient and is implemented in a wide range of commercial software. The time frequency analysis is uses in a wide range of signal processing applications . Because it can turn a recorded signal into an easily interpreted picture. It can serve as a powerful tool for linking physical phenomenon into features of time domain response data.