EE430 Term Project Part 1

In this part of the project, you are going implement a computer program that computes and displays the short-time Fourier transform (STFT) of a time-domain signal. Your program must be able to work with various inputs such as computer-generated data, audio files that are already existing in the computer storage, and sounds that are recorded by the user from a microphone.

Prepare a descriptive and a clearly written (in language and format) report. This report will be a part of your final project report and it will be collected at the end of the semester. Get prepared for the demonstrations which will happen within few weeks. You are going to upload your working code to ODTUCLASS at the day of your demonstration.

The sections below describe the tasks in more detail.

Data acquisition

Sound data from a microphone

System should capture the voice of the user or an audio playback from another device (e.g. mobile phone) by the help of a microphone connected to the computer. Analog-to-digital conversion sampling rate of this process should be adjusted from a user interface. The user must be able to play the captured audio input on the speaker of the computer.

Sound data from a file

The system should also be able to process wav or mp3 sound files. In each case, you must obtain the time-domain signal and the sampling frequency. For the files that contain multi-channel data (such as stereo music) you may choose to work with a single channel.

Data generation

The system must be able to generate the samples of time-domain signals with some simple mathematical expressions. The sampling frequency is always a user parameter. The total length of the generated data is also a user parameter. This can be input in seconds or in number of samples.

Some example for the signal types are given below. The user must be able to observe the time-domain or frequency-domain plots.

Sinusoidal signal

Parameters: Amplitude, frequency and phase.

Signal expression:

$$x(t) = A\cos(2\pi f t + \theta)\,.$$

Windowed sinusoidal

Parameters: Amplitude, frequency and phase. Name of the window function or the samples of it. The starting time and the length.

Signal expression:

$$x(t) = w(t - t_0)s(t - t_0)$$

where $w(t) = 0$ for $t \notin [0, \Delta)$ and

$$s(t) = A\cos(2\pi f t + \theta)\,.$$

Note that if *rectangle window* is selected, then the generated signal must be of the form

$$x(t) = \begin{cases} A\cos(2\pi f(t - t_0) + \theta)\,, & t_0 \leq t < t_0 + \Delta \\ 0, & \text{otherwise}\,. \end{cases}$$

Rectangle windowed linear chirp

Parameters: Amplitude, initial instantaneous frequency, bandwidth, duration and phase.

Signal expression:

$$x(t) = s(t - t_0)$$

where

$$s(t) = \begin{cases} A\cos\left(2\pi\left(f_0 t + \frac{m}{2\Delta}t^2\right) + \theta\right), & 0 \leq t < \Delta\,, \\ 0, & \text{otherwise}\,. \end{cases}$$

Signal involving multiple components

Parameters: Number of components, amplitude for each component, phase for each component, …

Signal expression:

$$x(t) = \sum_{m=0}^{M-1} x_m(t)\,.$$

Spectrogram

You are going write a MATLAB code to display the spectrogram of a discrete-time signal. A spectrogram is a color or grey scale plot of the magnitude of the short-time Fourier transform (STFT) on the time-frequency plane. One axis of time-frequency plane is time and the other is frequency. The third dimension is for the magnitude of the short-time Fourier transform.

How to obtain STFT of a signal?

Somewhat informally, let $w[n]$ (window function, tapering function) be a discrete-time sequence having a finite duration centered around $n = n_0$. For example, if all samples of $w[n]$ are the same then it is called a *rectangular window*[1]. Let $x[n]$ be the signal you wish to analyze. By multiplying $w[n]$ and $x[n]$ you extract a portion of $x[n]$ around n_0. Doing so, one focuses on the spectral properties of $x[n]$ over a particular time interval. Then, compute the magnitude of the discrete Fourier transform[2] (DFT) of the product. This is considered as a spectral description at time n_0. The magnitude values of this DFT can be coded in color or grey scale and plotted on the time-frequency plane (take horizontal axis as time and vertical axis as frequency). Proceeding with a sequence of n_0 values, a spectrogram can be plotted. The window length and the amount of shift between consecutive windows are the

[1] There are other well-known window functions like Hamming, Hanning, Tukey, Cosine, Triangular, Gaussian, Blackman, Kaiser…

[2] DFT values are the samples of DTFT.

fundamental parameters. The shift of the window should at most be equal to its length. The type of window function is also important. It has a significant role in some tasks.

Note that MATLAB has its own “spectrogram” command. You are going to write your own. You may use all other MATLAB commands. You can compare your results to those of MATLAB and other tools you can find from the web.

A signal and its spectrogram are shown in Figure 1 and Figure 2, respectively. Note that the horizontal axes (time) in both figures have the same scale.

Figure 3 and Figure 4 display the detail views of the signal around the time instants indicated by the white lines in Figure 2 on the left and right, respectively.

The magnitudes of the STFTs computed at the time instants indicated by the white lines in Figure 2 are shown in Figures 5 and 6.

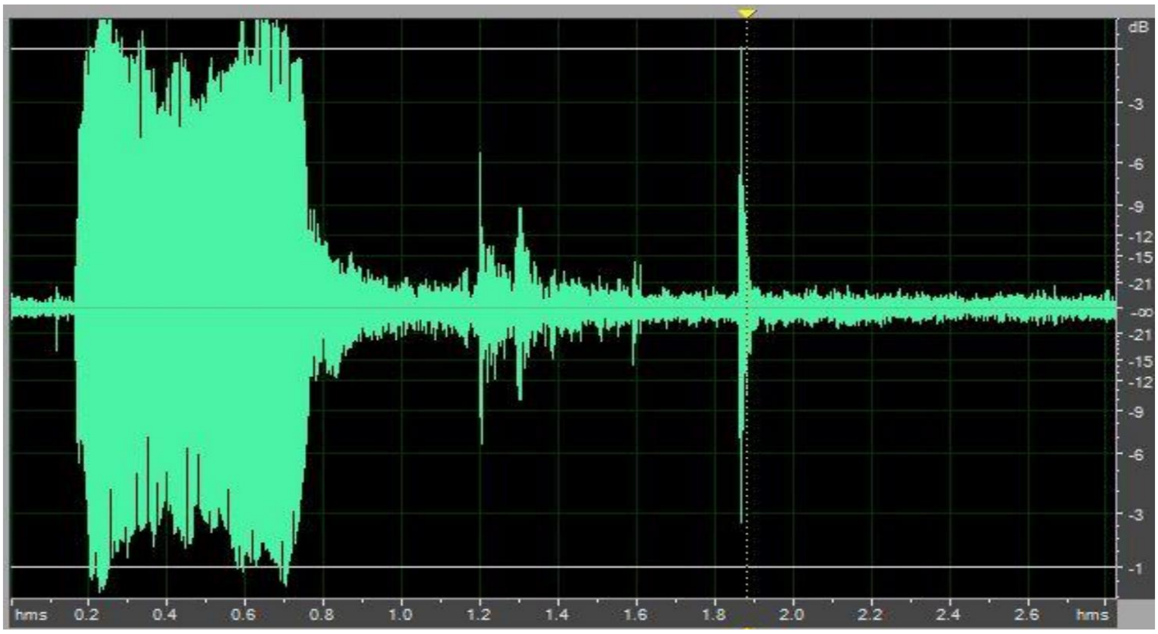

Figure 1: A signal to be analyzed.

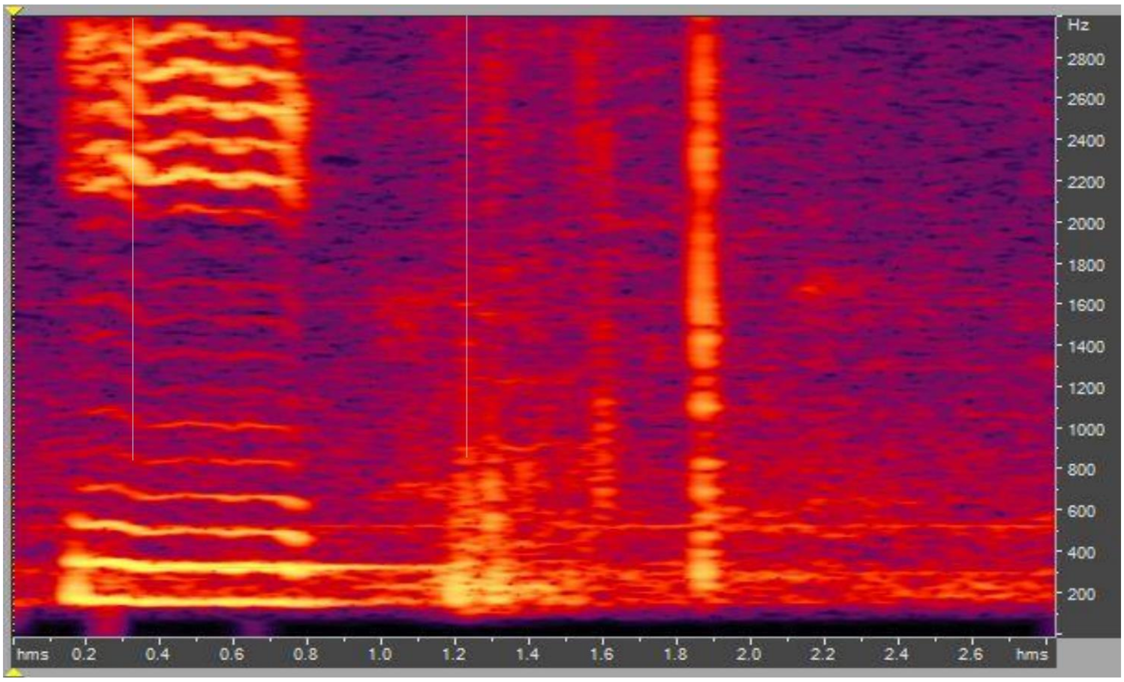

Figure 2: Spectrogram of the signal in Figure 1.

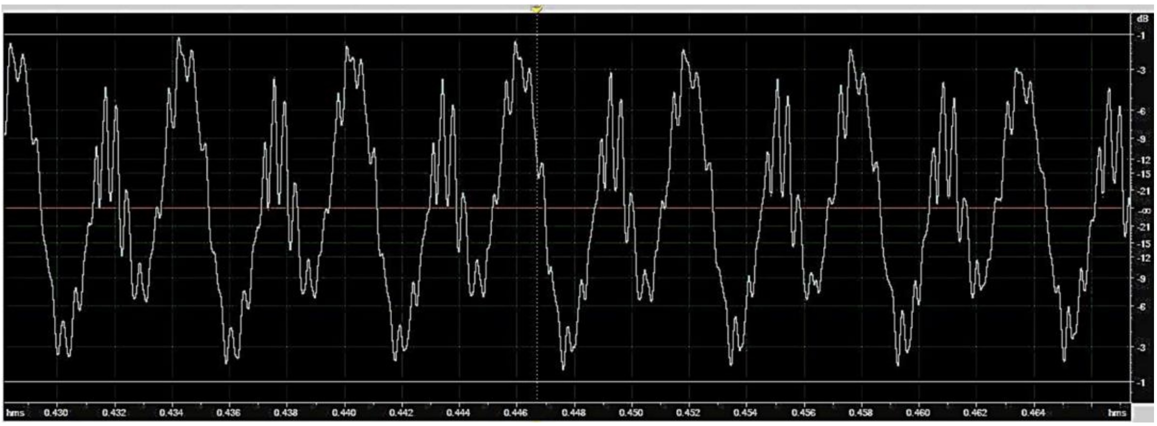

Figure 3: The signal details around the time instant of the white line on the left in Figure 2.

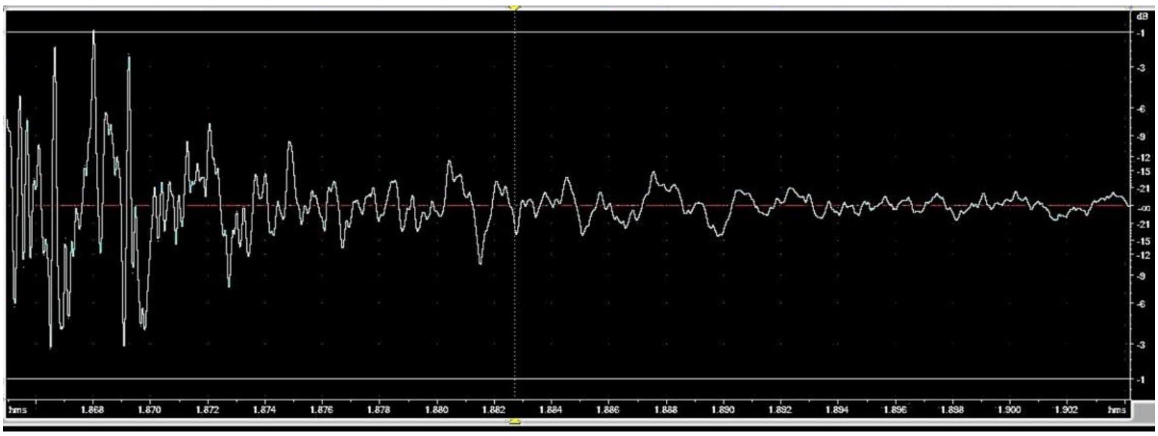

Figure 4: The signal details around the time instant of the white line on the right in Figure 2.

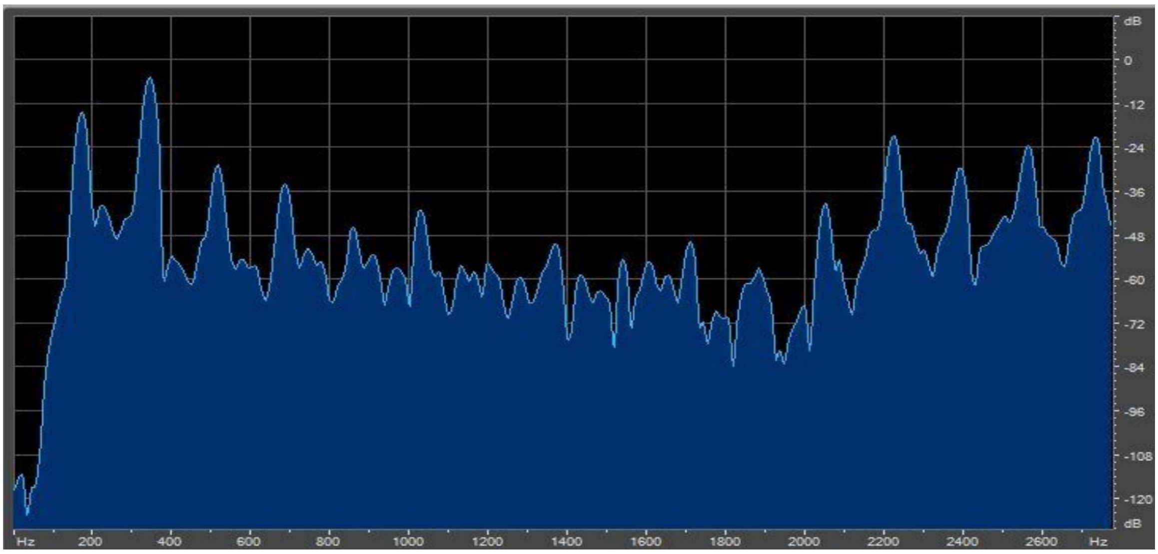

Figure 5: Magnitude of the STFT computed at the time instant indicated by the white line on the left in Figure 2.

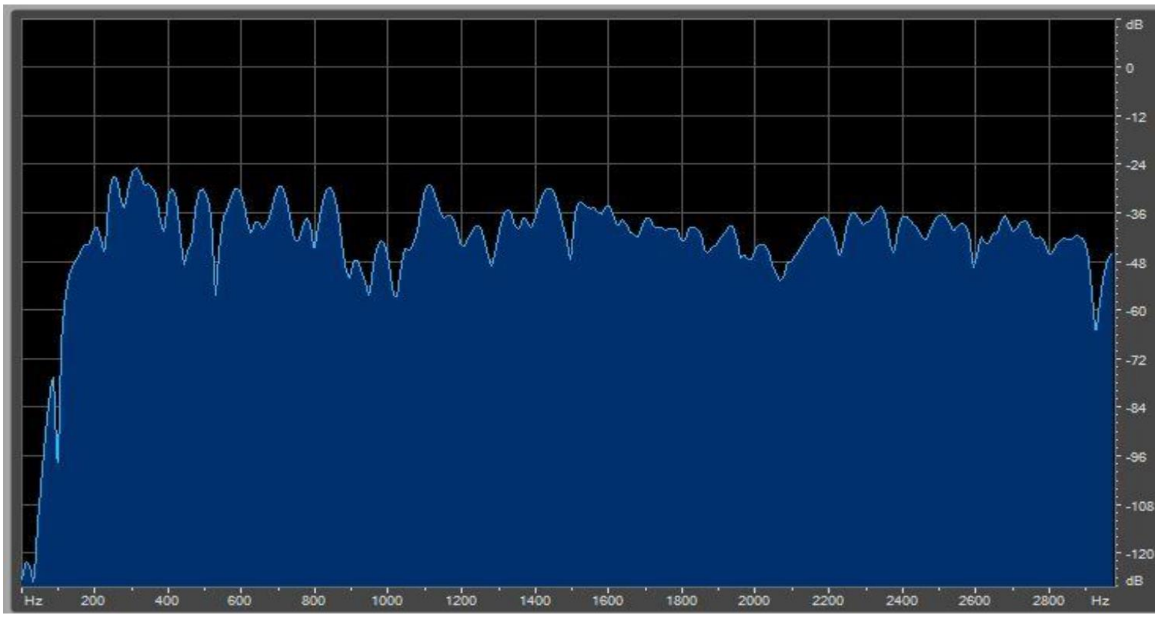

Figure 6: Magnitude of the STFT computed at the time instant indicated by the white line on the right in Figure 2.

Implementation:

Things to do:

- In your spectrogram code, window length and window type must be variable. For window type, use the alternatives (Hamming, Hann, Tukey, Cosine, Triangular, Gaussian, Blackman, Kaiser…) provided by MATLAB.
- Try different window lengths and state the differences of the spectrograms obtained by using different window lengths.

- Try different amounts of window overlap and state the differences of the spectrograms obtained by using different amounts of window overlap.

For the above, use at least the following data:

1. Recorded speech data.

2. Music data

3. Computer generated (windowed) sinusoidal waveforms.

4. Try signals with more than one sinusoidal components. What happens when the frequencies of the different components are close to each other? What happens when the window lengths change? (Note that the window (nonzero part) of the generated signal and the window of the spectrogram analysis are unrelated in general and they need not be the same.) Play with various data and analysis parameters. Show the results and comment on the important points.