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EC431H1 Digital Signal Processing
LAB 2.
The STFT and FFT. Applications to Signal Filtering and Detection.

Introduction

The purpose of this experiment is to become familiar with utilization of the Short-time Fourier Transform for discrete time signals and its implementation via FFT (Fast Fourier Transform) in DSP applications. The STFT will be used to provide information that can help recover a hidden signal via filtering , and can help to detect the presence of a signal burried in noise and interference. It is recommended that you use MATLAB to program and execute the required steps of the experiment. Your lab report (one per group of two students, 5 page approximately) should include: a)printouts of your programs, b) printouts/plots of the obtained results, and c) answers to questions and brief but critical discussion of the obtained results.

Experiments

PART A. Short Time Fourier Transform and FFT.

We have given the discrete signal

$$y[n] = x[n-260] + x_i[n] + w[n], \qquad n = 0, \ldots, 511$$

where

$$x_i[n] = \cos(0.3 \cdot \pi \cdot n), \qquad n = 0, \ldots, 511$$

$$x[n] = \cos(0.6 \cdot \pi \cdot n), \qquad n = 0, \ldots, 40, \qquad \text{(zero otherwise)}$$

and $w[n]$, $n = 0, 1, \ldots, 511$ is zero mean white Gaussian noise of $\sigma = 0.8$.

The above signal model considers a 'desired'signal $x[n]$ subject to background noise $w[n]$ and interference $x_i[n]$. The Signal to Interference noise Ratio (SINR) which is defined as the ratio of signal power to noise plus interference power, in dB, provides a measure of the severity of unwanted components in the oberved signal.

1. Write a little routine to generate and store the samples $y[n]$ for $n = 0, 1, \ldots, 511$. Plot $y[n]$. Calculate and plot the magnitude of the 512-DFT (via FFT), $Y[k]$, of $y[n]$. Also, calculate the SINR. How clearly can you detect the presence of $x[n]$ by looking at either $y[n]$ or $|Y[k]|$?

2. Using a rectangular window $R_{23}[n]$, $n = -11, \ldots, 0, \ldots, 11$ calculate the spectogram $|S_y(m,k)| =$ $|$512-DFT$(R_{23}[n-m] \cdot y[n])|$, $m = 12, 13, \ldots, 500$, $k = 0, 1, \ldots, 511$.

3. Draw a 2-D contour diagram of $|S_y(m,k)|$ of at least 20 levels (For example, using the MATLAB function, contour($|S_y(m,k)|, 20$)). Can you this time detect the presense of $x[n]$ and localize it both in frequency and time? Repeat the experiment by changing the length of the sliding window and comment accordingly.

PART B. Filtering

Given the signal $y[n]$ from part A, we wish to filter out noise and interference and extract $x[n]$.

1. To obtain $x[n]$ from $y[n]$ we will use a bandpass filter with impulse response

$$h[n] = 0.2 \cdot \cos(0.6 \cdot \pi \cdot (n - 50)) \cdot \text{sinc}(0.1 \cdot (n - 50)), \qquad n = 0, 1, \ldots, 100$$

. Plot $h[n]$ and its 512-DFT $|H[k]|$.

2. Filter $y[n]$ with $h[n]$. You may use either time domain processing , e.g. convolution, or frequency domain processing (by taking forward and inverse FFTs). Compare your result to $x[n]$ and comment appropriately. If you are not satisfied try to modify the bandpass range of the filter (how?) and repeat the filtering process.

3. The STFT from part A, provides you with both frequency and time localization information. Thus, a lot of the noise energy present in the frequency range of $x[n]$ can be removed by time filtering. Try again to reconstruct $x[n]$ by applying a two tier procedure. First, retain only the time samples of $y[n]$ where $x[n]$ is most probably located. Then, apply bandpass filter with the filter of the previous step. Compare the result with that of the previous step and comment appropriately.

PART C. Detection

The purpose of detection is to decide with some degree of certainty the presence of a desired signal within an observed signal in this case whether $x[n]$ is within $y[n]$. The STFT of part A, accomplishes that to a degree by revealing the presence of signals not detectable in time or Fourier Transform domain. However, it cannot tell us with certainty whether the actual signal is present. (For example, we know from the STFT that there is energy at that frequency over that time interval, but we do not know if it is from a cosine, or some other kind of signal). For that we may need additional processing with other algorithmic procedures. For example, we may use the crosscorrelation between the observed and desired signal (as we have defined it in Lab 1.)

1. Obtain the crosscorrelation $C_{y,x}(m)$ between $y[n]$ from $x[n]$ as follows:

$$C_{y,x}[m] = \sum_{n=0}^{40} y[m+n] \cdot x[n] \qquad m = 0, 1, \ldots, 472$$

   A sharp peak in the crosscorrelation will indicate the presence and location of $x[n]$ in $y[n]$.

2. Repeat the previous step by crosscorrelating $x[n]$ with the filtered signal of part B.2.

3. Repeat the previous step by crosscorrelating $x[n]$ with the filtered signal of part B.3.

Compare the results and comment appropriately.