ECE 340
Discrete Time Signals and Systems
Lab. 5
Filtering Multimedia Signals Using an FIR Filter

Outline of the Lab

In Lab 4, you looked at a noisy audio signal and a noisy image signal, and did the power spectrum analysis. In this Lab, you will apply digital filters to these signals and analyze the effect certain filters have. Note that a digital filter is a discrete-time system that transforms the frequency spectrum of a signal in a specified way. In digital signal and image processing, digital filters are widely used for various tasks such as reshaping of the frequency spectrum and noise removal.

1. (a) Using the MATLAB `fir1` function, design a 513-tap lowpass FIR filter with a cut-off frequency of 2500 Hz. Choose an appropriate truncation window such that the stopband ripples of the frequency response do not exceed -50dB. Assume a sampling frequency of 22050 Hz. A sample code is given below. Initialize appropriate filter parameters.

```
wc=fc/(Fs/2);
% fc: The cut-off frequency of the filter
% Fs: Sampling frequency of the audio signal
window = hamming(513);
% Truncation window function, using Hamming window.
% Other truncation window types may also be applicable. Please use
% Matlab help to find more applicable truncation windows.
filter_coeff=fir1(513-1, wc, window);
% filter_coeff: Coefficients of the FIR filter
```

   (b) Plot the frequency response of the filter. You may use the MATLAB `freqz` function to calculate the frequency response. A sample code is given below. Initialize appropriate filter parameters.

```
freqz(filter_coeff,1); %The frequency response of the filter
```

   (c) Read the audio signal `love_mono22.wav` used in Lab 4.

   (d) Pass the audio signal through the filter and calculate the output signal. A sample code is given below.

```
x_filtered=filter(filter_coeff,1,x);
%x_filtered: The filtered signal
```

   (e) Calculate and compare the spectrum (use the `pwelch` function) of the input and output signals and compare the two.

   (f) Save the modified output signal as .wav file and play it with any media player.

   (g) Listen to the original and filtered signals and comment on their difference.

2. (a) Using the MATLAB `fir1` function, design a 513-tap highpass FIR filter with a cut-off frequency of 5000 Hz. Choose an appropriate truncation window such that the stopband ripples of the frequency response do not exceed -50dB. Assume a sampling frequency of 22050 Hz.

   Repeat steps (b)-(g) of Q1.

3. (a) The audio signal is corrupted by a noise. From the frequency spectrum of the noisy audio signal, determine the frequency range in which most of the noise's energy located (in kHz). Based on your observations, use the MATLAB `fir1` function to design a 513-tap FIR filter to remove the noise in the audio signal. Choose an appropriate truncation window such that the stopband ripples of the frequency response do not exceed -50dB. What type of filter (lowpass, highpass, bandpass, band-stop) is it?

   Repeat steps (b)-(g) of Q1.

4. In Lab 4, you used a noisy image `ayantika.tif`. The spectrum analysis in Lab 4 showed that the rectangular grid noise is due to the 4 peaks in the mid-frequency region of the power spectrum. It is possible to eliminate the noise by designing an appropriate band-stop filter which will just eliminate the noise frequencies. In this question, we will use another approach where we will use the following lowpass filter

   ```
   filter_coeff = [1  2 3 2 1; 2  3  4  3 2; 3  4  5  4 3; 2  3  4  3  2; 1  2  3  2 1]/65 ;
   ```

   which stopband includes the noise frequencies.

   (a) Download the Lab5Q4.m MATLAB snippet and run it.
   (b) Go through the various plots and images and try to understand what is going on.
   (c) Comment on the plots and images. Explain why the filtered image looks like a very smooth version (the edges are not very sharp) of the original image.