Assignment: Homework 1

What to Hand It In

1. Your code with appropriate comments and a **readme file**. You are responsible for making us understand and know how to run your code.
2. **A report** with answers, figures, and explanations.
3. **Any sound files** requested in the problems.

How to Hand It In

1. Put all your files in one folder. Compress this folder and name it <firstname>_<lastname>_HW1.zip. For example, "Zhiyao_Duan_HW1.zip".
2. Submit via blackboard to the appropriate entry. You can make multiple attempts but only the last attempt will be graded.

When to Hand It In

It is due immediately at the beginning of the day (i.e., 0:00AM) specified on the course calendar. **Late assignments will receive a grade deduction of 20% of the full grade each day.**

Problems (10 points in total)

1. (2 points) Basics.
    a. (1 point) Read "Brahms.wav" using "audioread" function (or "wavread" if you use an older version of Matlab). What is the sampling rate of the signal? What is its bit depth? Calculate its RMS value and visualize the shape of its probability density function (PDF) using the "hist" function. What distribution does this PDF look like? Apparently this audio file is already quantized, but we will re-quantize it later.

    b. (1 point) Generate a 2-second-long sine wave with peak amplitude of 0.9 and frequency of 480 Hz. Use sampling rate of 48,000 Hz. What is the theoretical RMS value for such a sine wave? What is the actual RMS value calculated from this particular signal? Visualize its PDF. Now generate another 2-second-long sine wave with the same parameters, but with frequency of 513 Hz. Note that 480 Hz is a sub-multiple of 48,000, while 513 is not. We will use these two sine waves to see the regularity of quantization error.

2. (4 points) Quantization without dither.
    a. (1 point) Write a function called "my_quantizer" to quantize a signal to n bits. Implement both the midtread quantizer and the midriser quantizer. The syntax of the function is
    function xq = my_quantizer(x, n, bType)
    % x – input signal
    % n – quantization bit depth
    % bType – 0: midtread; 1: midriser

b. (1 point) Use your quantizer to re-quantize the 480 Hz sine wave with 4 bits using midtread. Plot 5 cycles of the original sine wav, the re-quantized sine wave, and the quantization error signal in the same figure with different colors. Save the original sine wave as "sine480.wav", and the re-quantized signal as "sine480_quan_4bits.wav" using the "audiowrite" function (or "wavwrite"). Listen to them. Do you hear any quantization noise or artifacts? What is the quantization SNR? Adjust the bit depth of your re-quantization to find the smallest bit depth that the quantization noise and artifact is not audible for you.

c. (1 point) Use your quantizer to re-quantize the 513 Hz sine wave with 4 bits using midtread. Save the original sine wave as "sine513.wav", and the re-quantized signal as "sine513_quan_4bits.wav" using the "audiowrite" function (or "wavwrite"). Listen to them. Is the quantization noise in the re-quantized signal audible? Does the noise sound different from that in the 480 Hz re-quantized signal? If you feel it's different, explain why.
Hint: you can plot the quantization error signal, or plot the Fourier transform magnitude spectrum (using "fft" function) to see some regularities for the 480 Hz sine wave.

d. (1 point) Apply your function to re-quantize "Brahms.wav" that you have read into Matlab in Problem 1 with a bit depth of 10. Plot the PDF of the error signal. Calculate the quantization SNR. Adjust the bit depth and listen to the sound. (You can use "soundsc" function to listen to the sound without saving it.) Try to find the smallest bit depth that you feel the quantization noise is not audible.

3. (4 points) Dither.
   a. (1 point) Generate a 2-second-long uniformly distributed (between -1/2 and 1/2) random dither signal with sampling rate of 48000 Hz. Plot the PDF to verify your result. What is its theoretical RMS value? What is its real RMS value?
   Hint: you may find rand() function helpful.

   b. (1 point) Generate a 2-second-long triangularly distributed (between -1 and 1) random dither signal with sampling rate of 48000 Hz. Plot the PDF to verify your result. What is the theoretical RMS value for a random signal with such a PDF? What is the actual RMS value for your particular signal?

   c. (1 point) Scale your dither signals so that its RMS value is 1/2 of the quantization step size. Apply the dither signal and perform the 4-bit midtread quantization using your program on the 480 Hz sine wave. Save the re-quantized signal as "sine480_quan_4bits_dither_uniform.wav" and "sine480_quan_4bits_dither_triang.wav", respectively. Does the quantization noise/artifact sound better than that without adding dither? Explain why.

d. (1 point) Try different quantization bit depths, different scales of your dither (e.g., 1/16, 1/8, 1/4, 1/2, 1, 2, 4, 8, 16 times of the quantization step), and different kinds of dither signals. You want to make the dither large enough to destroy the artifacts in the quantized signal, but not too large as it introduces dither noise. With your best parameter setting, plot the PDF of the quantization error signal. Plot the Fourier transform spectrum of the quantized signal. Discuss why you are satisfied or not satisfied with the result.