EE4634 – Analog and Digital Communications

Design Project 1

Sampling and Quantization

Sept. 14, 2007

Due Date: Sept. 28, 2007

1. First go to the web page http://www.mprg.org/people/buehrer/4634/ecpe_4634.htm and click on the Matlab link. Download the Matlab functions `bandwidth.m`, `EnergySpectralDensity.m`, `sample.m`, `uniformquantize.m`, `compress.m` and `expand.m`, and the data file `DesignProject1.mat`.
2. Save the functions in the directory in which you run Matlab.
3. Start Matlab.
4. The object of the project is to determine the best combination of sampling and quantization to (a) minimize data rate of the PCM version of a voice signal while (b) obtaining acceptable voice quality.
5. Load the data using the command
   >> **`load DesignProject1`**
   (Note that ">>" is the Matlab prompt. You do not need to type it.) We will be using a highly over-sampled (f_s = 65,536) version of the voice signal with a very high number of quantization levels to approximate the analog signal.
6. To examine the original file, type the commands
   a. **`>> sound(Original, 65536)`**; (plays the sound file)
   b. **`>> EnergySpectralDensity(Original, 65536);`** (plots the ESD) → Question: Why are we using the ESD and not the PSD?
   c. **`>> plot(time, Original);`** (plots the time waveform)
   d. What is the bandwidth of the original signal? [Use the Bandwidth.m function to determine the 99.9% energy bandwidth (i.e., the bandwidth that contains 99.9% of the energy)
7. Now let's examine the impact of sampling rate. To create a "sampled" version of the waveform type >> **`x = sample(Original, f_s);`** where f_s is the sampling rate you wish to use. Try several sample rates between f_s = 2048 and f_s = 16384. (Note: using a power of 2 is preferable but not necessary. It speeds up the computations.) Plot the spectrum of the sampled signals using the command: >> **`EnergySpectralDensity(x, f_s).`** (Note: Whenever your create a new vector **`y = f(x);`** make sure that you add a semicolon at the end. Otherwise, the result will be displayed on your screen and it will take a long time.) Note that you can change the axes on the plot using the zoom option on the figure window. For your report make sure to label the axes using **`xlabel('Label')`** and **`ylabel('Label')`**.
8. Listen to each signal using the command: **`>> sound(x, f_s);`** Note that the voice should play at normal speed (i.e., it shouldn't sound as if it were going too fast or too slow). If it isn't, you may not be using the function `sound()` properly.
9. What is the impact of the sampling rate on the sound quality? At what sampling rate does the voice quality begin to suffer? How does this compare to the theoretical minimum? (Use the 99.9% bandwidth as the absolute bandwidth).

Calculate the SNR by comparing the sampled signal to the original using the interp() function.

10. Now let's take a look at the impact of quantization. To quantize the signal create a new signal **`y = uniformquantize(x, levels);`** where **`x`** is your sampled signal and *levels* is the number of levels you wish for your quantized signal. Use a sampled version from above, not the original signal. Examine several values for levels between 2 and 1024. Please be patient with the **`uniformquantize()`** function. For large values of `levels` and long input vectors, it may take some time. If you wish to examine a part of the signal you can always define a portion of the signal as **`z = x(1:points);`** where ***points*** is the number of points you wish to examine. Listen to each of the quantized signals. Where do you think that the voice quality breaks down (i.e., how many bits are necessary to properly quantize the signal)? Plot the error signal. *Calculate the SNR for each case and compare to theory.* [Hint: Find the power in the original signal and the power in the error or noise. Since you know the unquantized signal you can calculate the noise power using the difference between the unquantized and quantized signals.]
11. Now let's examine the effect of amplifier gain control (i.e., the gain of the signal coming into the quantizer). Define a sampled signal **`x = sample( Original, 8192);`** Listen to the signal using sound(x, 8192); Now quantize the signal to 16 levels **`y = uniformquantize(x, 16)`**. Listen to the quantized signal. How does it sound? Try this again now using **`z = 2*uniformquantize(0.5*x, 16)`**; Listen to the new signal. How does it compare? Plot the error between x and y and the error between x and z. What are the differences? Now create **`w = 0.2*uniformquantize(5*x, 16)`**; Again, plot the error between **w** and **x.** How does this signal sound? Measure the SNR in all three cases. Describe the difference in the error between y, z, and w. What does this tell you about (a) the impact of improper gain control and (b) the importance of the different parts of the waveform?
12. Up until this point we have used a uniform quantizer. We will now examine the impact of non-linear quantization. Create a signal **`x = sample( Original, 8192);`** Also create a second signal **`y = compress( x, 255);`** This function will apply a μ-law compression characteristic to **x** with μ = 255. Quantize **x** and **y** with the uniform quantizer and 16 levels (**x_q**, **y_q**). Now expand the signal **y_q** (quantized version of y) using **`z = expand(y_q,255);`** Listen to z and x_q. Plot the error for both. Which sounds better? Explain. Calculate the SNR. How does the error compare?
13. Finally, suppose you were designing a system which would cost 1 cent/minute/kbit/sec. That is, a system design that resulted in 64 kbps would cost the consumer $0.64/minute. What is the best design (i.e., choices if f_s and quantization levels and compander/no compander) in your opinion? Justify your conclusion.
14. Write a short report including all of the data (e.g., plots) from the above steps. *In the report make sure that you answer any questions listed above. Also, be sure to include all formulas used*. Summarize your design and give a justification for it.

I have posted a sample report format that you can use if you wish. Note that your grade will be based on

a. Presentation (30%) – How well was your report organized? How well did you express your ideas? This portion of the grade is based on the quality of the report in terms of communication skills. You should treat this report as if your boss were going to read it. **The report should not be a simple listing of the steps performed, it should be written as a standard technical report.** One approach would be to have a major section devoted to the different aspects that were examined. In other words, one section could examine the impact of sampling rate, a second section could examine the impact of quantization, while a third section could discuss companding etc. Figures must be labeled and referred to in the text.
b. Technical Content (30%) – Did you understand your results? How well did you tie in theoretical concepts to your results? This portion of the grade is based on the technical accuracy of your report.
c. Completeness (30%) – Did you include all of the things that were required? This portion of the grade is based on the completeness of your results/report.
d. Conclusion (10%) – What did you learn? What are your conclusions based on the experiments? You need to succinctly summarize your findings and what they mean.