Signals and Systems

(10920EECS202002)

Computer Homework #1: Listen to sinusoidal signals, perform sampling, and experience system modeling and implementation

Due: 24:00, 03/18/2021

The goal of this homework is to warm up and give you a chance to be familiar with the sinusoidal signals commonly used in this course and commonly seen in real world, sampling, and get some feeling about system modeling and implementation from MATLAB programming. Typically, when listening to the sinusoidal signals and feeling the signals, you should be able to correlate their parameters, e.g., magnitude and frequency, to loudness and pitch of the sounds – linking math to real world, and figure out sampling criterion, e.g., the minimum required sampling rate. After going through this course, you may come back and think about anything you learn can be applied to this homework.

Given ComputerHW1_SampleCodes.m. The part of "Codes for problems 1 and 2" is used to emulate a continuous-time (CT) sinusoidal signal x(t) by its discrete-time (DT) counterpart x[n], which is obtained by sampling x(t) at sampling rate f_s (in Hz). The equations representing x(t) and x[n] are shown below.

$$x(t) = A\cos(2\pi f_0 t + \phi),$$

where A is a real number and larger than 0, representing the magnitude, f_0 is the frequency which is equal to 1/(fundamental period), in Hz, and ϕ is the phase.

$$x[n] = x(nT) = A\cos(2\pi f_0 nT + \phi),$$

where T is the sampling interval which is equal to $1/f_s$, in sec.

1. Connection between signal features and your ear/the sound you hear. Go through "Codes for problems 1 and 2" in ComputerHW1_SampleCodes.m, and try to (CAUTION: MAKE SURE the volume is moderately low to avoid hearing. 請注意測試輸出音樂時，小心音量控制，避免傷到聽力。此訊號最大的振幅(magnitude)為 1，人耳的靈敏度應該可以聽到 0.01-0.001 的聲音(端看你喇叭音量開多大)，請小心測試)
   (a) (10%) Demonstrate that $x(t)$ is a periodic signal and f_0 is truly the frequency via MATLAB graphic illustration as well. As for the MATLAB graphic demonstration, I mean that plot $x(t)$ and $x(t+1/f_0)$ and show the two signals are exactly the same (had better include a plot of the difference of the two).

(b) (10%) Assign the values of 0.25 and 1, respectively, to the variable **A** while keeping all the other variables as default (i.e., don't modify the other codes). Please tell the changes in the signal by observing the plots and by listening to the sounds as well when the variable **A** goes from 0.25 to 1. Plot the signals with different values of **A** in one plot to illustrate your findings.

(c) (10%) Assign the values of 256, 512, and 1024, respectively, to the variable **f0** while keeping all the other variables as default. Please tell the changes in the signal by observing the plots and by listening to the sounds as well when the variable **f0** goes from 256 to 1024. Again, plot the signals with different values of **f0** in one plot to illustrate your findings.

(d) (10%) Assign the values of 0, $\pi/8$, $\pi/4$, $\pi/2$, π, $3\pi/2$ and 2π, respectively, to the variable **phi** while keeping all the other variables as default. Please tell the changes in the signal by observing the plots and by listening to the sounds as well when the variable **phi** goes from 0 to 2π. In addition, tell what type of transformation of the independent variable (i.e., time shift, time reversal, and time scaling) the changes correspond to, and justify your answer via the plots and more specifically via a mathematical equation showing the relationship between the phase ϕ and the corresponding transformation of the independent variable.

Is there any limitation for such a transformation to a sinusoidal signal by change of the phase ϕ? If your answer is yes, please describe the limitation.

2. Sampling a sinusoidal signal. Go through "Codes for problems 1 and 2" in ComputerHW1_SampleCodes.m, and answer the following questions.

(a) (10%) Change the value of the variable **fsRatio** from 20 down to 1.2 while keeping all the other variables as default. Note that you at least must try **fsRatio** = 20, 4, 2.5, 2.2, 2, 1.8, 1.4, and 1.2. Assume that the sound with **fsRatio** = 20 played by your computer sound card is the correct sound for x(t). Listen to the sounds when **fsRatio** goes from 20 down to 1.2 and tell your findings. More specifically, tell with what values of **fsRatio** (or with what sampling rate) you can hear the correct sound of x(t). You may justify this finding via the plots of x[n] with different **fsRatio** values. (You can google "how sound cards work" if you are interested).

(b) (10%) Following (2a), what feature of the sinusoidal signal x(t) (i.e., magnitude A, frequency f_0, or phase ϕ) has been changed after the sampling so that you hear the incorrect sound? According to the computer experiments in (2a), comment on what is the smallest **fsRatio** (i.e., the smallest sampling rate) which allows you to hear the correct sound, that is, keeps the above recognized feature unchanged.

Supposedly, now you can answer the following questions which I raised in class.

Under what sampling rate will the DT sinusoidal signals from sampling a CT sinusoidal signal preserve key properties of the CT signals so that the CT signals can be reconstructed from their DT counterparts?

What do you think are the key properties?

(c) (10%) If you carefully exam all the sampled sinusoidal signal, i.e., the DT sinusoidal signal x[n] via the plots, you will find out that all x[n] with the fsRatio values mentioned in (2a) are periodic signals. Does it mean that all the sampled sinusoidal signals x[n] are periodic signals? If your answer is no, please tell with what values of fsRatio, the DT sinusoidal signal x[n] is not periodic and verify your answer by plotting the aperiodic x[n].

3. Deciphering MATLAB codes into system models (i.e., mathematical operations).
   (a) (10%) Go through "3(a)" of "Codes for problem 3" in ComputerHW1_SampleCodes.m, and try to write down the 1D system model (i.e., difference equation converting input to output) used to process each row (i.e., input signal) of the provided Lena image (i.e., lena.jpg). Verify whether the 1D system is causal, linear and time invariant or not, tell what the system does to each row of Lena image and elaborate the reason why.
   (b) (10%) Similar to (a), go through "3(b)" of "Codes for problem 3" in ComputerHW1_SampleCodes.m, and try to write down the 1D system model (i.e., difference equation converting input to output) used to process each row (i.e., input signal) of the provided Lena image (i.e., lena.jpg). Tell what the system does to each row of Lena image and elaborate the reason why. Again verify whether the 1D system is causal, linear and time invariant or not. If it is not causal, please remodel it into a causal form with the same function to each row and implement the causal system you model.
   (c) (10%) go through the codes in "3(c)" of "Codes for problem 3" in ComputerHW1_SampleCodes.m, and try to write down the corresponding mathematical operations (including equations and the name of these operations taught in the course lectures) to each row of Lena image.

Notice:

1. Please hand in your solution files to the LMS elearning system, including your word or pdf file of the detailed solutions/report, the associated MATLAB codes,

and all the related materials. It would be nice that you can put your “KEY” code segment with comments side by side along with your answer in the word or pdf file if needed.

2. Name your solution files “EECS2020_HW1_StudentID.doc” (or “EECS2020_HW1_StudentID.pdf”) and “EECS2020_HW1_StudentID.m”, and archive them as a single zip file: EECS2020_HW1_StudentID.zip.
3. The first line of your word/pdf or Matlab file should contain your name, student ID, and some brief description, e.g., % EECS2020 Calvin Li student ID Computer HW1 MM/DD/2021