MEMO Number CMPE323-Lab01

DATE: August 17, 2016
TO: CMPE323
FROM: EFC LaBerge
SUBJECT: Sampling for Models and Simulation

1 INTRODUCTION

Today, almost all simulation of linear and non-linear systems is performed by means of a digital computer, using software such as MATLAB. Because the computations within a digital computer are, by their very nature, discrete time with quantized amplitudes, we need to pay attention to sampling issues. That is, we need to correctly translate the analog time of the system we are modeling to the discrete time system that we a simulating in a manner that retains the important characteristics of the analog system. This lab is an introduction to the concept of sampling and modeling analog signals. Similar techniques can be applied to modeling analog systems, as well.

All sample mechanisms – whether we're sampling in space or in time or in some other dimension – are governed by the Shannon Sampling Theorem:

> An accurate discrete time model of an analog (continuous time) waveform can be obtained **if and only** if the discrete time model has a sample rate that is at least **twice** the highest relevant frequency in the analog waveform.

The minimum rate associated with this Theorem, that is, "twice the highest relevant frequency" is known as the **Nyquist Rate**. The frequency associated with this Theorem, that is, "the highest relevant frequency", is known as the **Nyquist Frequency**.

2 EQUIPMENT

For this lab, you need a laptop with MATLAB installed.

For the purpose of CMPE323, please use the following naming conventions for all output files:

CMPE323F16_Lab<Lab#>_<Your Campus ID>

For the purpose of CMPE323, please use the following naming conventions for MATLAB scripts or functions that you are required to submit.

<function name>_<Your Campus ID>

Examples will be given in the lab description. Follow the instructions exactly, or you may not get graded!

3 LAB TASKS

You might find it useful to use the MATLAB function `diary` to capture your inputs and outputs.

3.1 Examples of the Sampling Theorem

3.1.1 Simple Sine Wave

Using a simulation sample rate of 100 Hz, create and plot a one Hertz cosine. Use a range of times that includes both negative and positive times. Use proper scaling and axis labeling conventions. When we are trying to simulate or model an analog waveform, we typically use sample rates of 50 to 100 times the Nyquist Rate. What is the Nyquist rate for this waveform, and does this sample rate meet that standard of practice? Make sure your plot is titled with both the actual sample rate and the Nyquist Rate.

Repeat the previous exercise with a simulation sample rate that is equal to the Nyquist Rate. Does your plot make sense? Why? Try again with a sine wave (instead of a cosine wave). Does your plot make sense? Why?

Repeat the previous exercise with a simulation sample rate of 0.75 times the Nyquist Rate. Comment on the observed periodicity? Does the simulated waveform match the intended 100 Hz sinusoid? If not, what is the apparent period and frequency of the sampled waveform.

3.1.2 Complicated Sinusoid

Repeat the exercise of 3.1.1 with a Double Sideband Amplitude Modulated (DSB-AM) waveform given by the equation

$$x(t) = 1 + 0.25\sin(180\pi t) + 0.15\sin(300\pi t) + 0.4\sin(2040\pi t)$$

22* MERGEFORMAT ()

Choose your simulation sample rate to be 100 times the Nyquist frequency for this waveform, and choose the time span to include at least five cycles of the resultant periodic waveform. (How do I know it is periodic?).

When you sample at the Nyquist Rate, what elements of the waveform are well preserved? What elements are not well preserved. What does this tell you about sampling at or near the Nyquist Rate for this particular waveform?

3.2 Sampling Edges

The Shannon Sampling Theorem also implicitly defines how well we can determine sharp edges in our simulation. Consider simulation of the unit step function

$$u(t) = \begin{cases} 1 & t \geq 0 \\ 0 & t < 0 \end{cases}$$

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(Note that I've defined the value at $t = 0$! We'll deal with this more rigorously later). We'll find out that this signal has energy at ALL frequencies so there is no "maximum frequency". Therefore, we *can't* choose a proper Nyquist Rate. What now?

In this case, we pick the sample interval to be a small fraction (<10%?) of the time measurement we wish to make. Our residual time uncertainty is equal to the sample interval. So if I'm interested in knowing the time position of the leading edge of my unit step (or pulse) within 1 ms, my samples should be spaced at least 0.1 ms apart, or a sample rate of 10 kHz.

3.2.1 Modeling a unit pulse

Create an anonymous function to create a unit step function. Then create a second anonymous function using the first to create a unit-amplitude pulse of duration *T*. Use your unit-amplitude pulse to model and plot the following.

Using a sample time of 0.1 seconds, create and plot the unit pulse $p(t;T) = u(t) - u(t-T)$, with $T = 1$ sec for $-1 \leq t \leq 4$ seconds.

Create and plot the unit pulses $p(t-0.5)$, $p(t-0.1)$, $p(t-0.0525)$, and $p(t-0.113)$. For each pulse determine the time coordinate of the first non-zero sample. *Hint: Use the MATLAB function* `find`. What do you notice about the times?

3.2.2 Measuring the leading edge

Use the MATLAB function rand to generate 10,000 uniform random numbers between 0 and 1. Then scale these random numbers to be between 0 and 0.1. For each of the random numbers compute the pulse $p(t-r_k)$, where r_k is the random value, and *t* has the same range as in 3.2.1. Determine the time coordinate of the first non-zero sample for each of the computed pulses. Find the minimum, maximum, mean and standard deviation of these time coordinates. *Hint: Use the MATLAB function* `min`, `max`, `mean`*, and* `std`.

Repeat this experiment with a sample time of 0.05 seconds. Don't forget to rescale the random numbers.

In both of the experiments, the leading edge of the pulse should be at $t = 0$. Comment on the errors you measured, based on the sample times. If necessary, repeat for other sample times of your choice.

4 LAB SUBMISSIONS

Submit the following via the Blackboard assignment Lab 1.

In a single PDF file named in accordance with the output naming conventions given above, include

a. The outputs generated in 3.1.1

b. Answers to the questions posed in 3.1.1, properly referenced to the figures.

c. The outputs generated in 3.1.2

d. Answers to the questions posed in 3.1.2, proper referenced to the figures.

e. The plots generated in 3.2.1, the times you measured, and some discussion.

f. A table containing the results (min, max, etc) of 3.2.2, including any other offset values you considered and an accompanying discussion.

g. Your conclusion about sampling fast-rise-time pulses.

Please use this file as the template for your report. Submitted plots should have figure numbers and titles, done in Word, in addition to any labeling in MATLAB. (*Hint: It's not a good idea to do the figure numbering in MATLAB, as a change in location of the figure means you have to replot and relabel.)* As part of your answers to the questions, provide a sentence or two describing the key features of each plot.

Lab 1 is due at 8:59 AM on Friday, September 16.