A TIMS Based Laboratory for Undergraduate Probability and Random Processes

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Introduction

The Department of Electrical Engineering at the University of Nebraska has implemented an Integrated Signals and Systems Laboratory (ISSL) based on a single experimental platform throughout a sequence of four courses at the junior and senior levels [1]. This laboratory is funded by a Course, Curriculum and Laboratory Improvement (CCLI), Adaptation and Implementation (A&I) track, grant from the National Science Foundation. The four-course sequence is ELEC 304 Signals and Systems, ELEC 305 Probability and Random Processes, ELEC 462 Communication Systems, and ELEC 464 Digital Communications. The laboratory platform chosen for the ISSL is the Telecommunications Instructional Modeling Systems (TIMS). This paper describes how the laboratory is being used in the junior level course ELEC 305 Probability and Random Processes.

ELEC 305 is a required three credit hour course in the undergraduate curriculum in the Department of Electrical Engineering with course objectives that emphasize the fundamentals of axiomatic probability theory and random processes and their application in electrical engineering disciplines. ELEC 305 has significant mathematical and theoretical content and is a prerequisite course for senior level elective courses in communications systems and signal processing. Course evaluations reveal that students typically view this course as a math course with no practical application. In addition, this course has a very rate of recidivism. Faculty teaching subsequent communications systems and signal processing electives generally find that students do not retain content from ELEC 305. In an attempt to address both perspectives, we are using our TIMS based ISSL to add a laboratory component to ELEC 305.

There are two overall objectives for introducing a laboratory component to ELEC 305. First, it is desired to increase student outcomes with respect to the ELEC 305 course objectives. Second, the laboratory provides continuity in the four course sequence and it desired to increase concept retention from course to course.

Laboratory Implementation

The ISSL consists of several identical laboratory stations with each station consisting of a TIMS unit, a 4-channel oscilloscope, a network analyzer, a signal generator and a computer. All the test and measurement equipment is connected to the computer via an IEEE-488 bus that enables screen captures and subsequent printing. The computers can also be used for real time lab reporting.

The laboratory component is integrated into the course without adding additional credit hours. The laboratory experiments are assigned and graded in essentially the same manner as traditional homework assignments. Each laboratory assignment requires a brief written report that consists of responses to questions posed in the laboratory protocol, concise discussions of the results, and printouts of the oscilloscope and spectrum analyzer displays. Students typically write the report as they are performing the laboratory and submit it via email. A formal laboratory report is not required. Each laboratory experiment is designed to take approximately 90 minutes. This laboratory does not have a teaching assistant and students have 24-hour access to the laboratory via electronic locks. The laboratory stations are assigned on a first come, first served basis and they may not be reserved.

Laboratory Experiments

There are currently four laboratories written for ELEC 305. The guiding principle behind these laboratories is that they should clearly illustrate a particular concept of probability and random processes. The physical world and the laboratory are obviously time based systems, so the experiments naturally emphasize random process concepts. In what follows we describe two of the four experiments that have been developed. All the laboratories may be downloaded from the first author's website.

I. Random Signals and Power Spectral Density

The objective of this laboratory is to allow the students to explore the relationship between the mean and variance of a stationary random process and its time domain and frequency domain (power spectral density (PSD)) representations. This is accomplished using the TIMS (bandlimited) Noise Generator module, a DC signal and the TIMS Adder module. The noise generator (approximately) outputs a zero mean Gaussian random process $n(t)$ and a variable DC signal is added to this to adjust the mean of the process. The resulting process $w(t)=n(t) + V_{DC}$ is then observed on the oscilloscope and a spectrum analyzer. The oscilloscope display of $w(t)$ with V_{DC}=0 is shown in Figure 1.

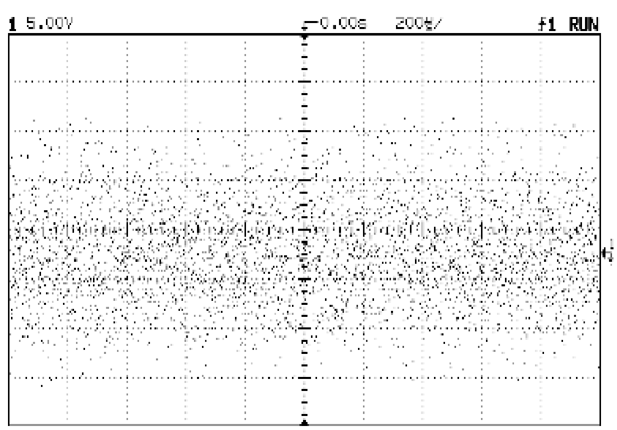

FIGURE 1
OSCILLOSCOPE PLOT OF A RANDOM NOISE SIGNAL.

In order to calculate the mean of the process, the students are instructed to turn on the averaging feature of the oscilloscope. This results in the signal shown in Figure 2 from which it can easily be discerned that the mean is zero. This experiment reinforces the concept that the mean of a random process is equivalent to its DC value and also introduces the notion of noise reduction by averaging which is further explored in a later laboratory.

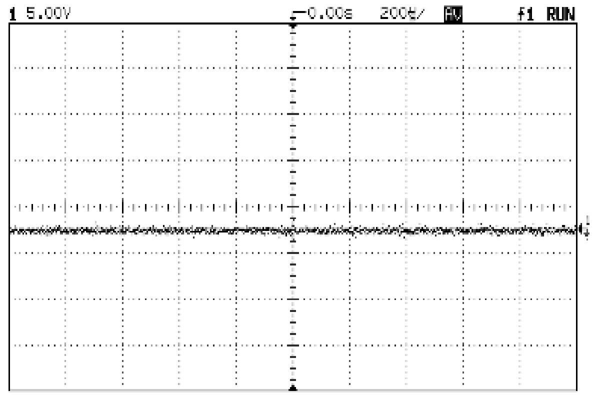

FIGURE 2
OSCILLOSCOPE PLOT OF A TIME AVERAGED RANDOM NOISE SIGNAL.

In order to compute the variance of *w(t)*, the students are instructed to observe the PSD of the signal on a spectrum analyzer and to compute the area under the resulting display. An example of this is shown in Figure 3. The variance computed using the PSD is then compared to the sample variance computed using MATLAB. (The agreement between these measurements is quite good.) This part of the experiment introduces PSD in a familiar manner as they have used the spectrum analyzer to determine the frequency content of deterministic signals in the prerequisite course ELEC 304. The random process *w(t)* is then filtered using the TIMS Tunable LPF module and the variance recomputed via the PSD. Since the spectrum analyzer does not measure DC content, this laboratory also reinforces the interpretation of variance as AC power.

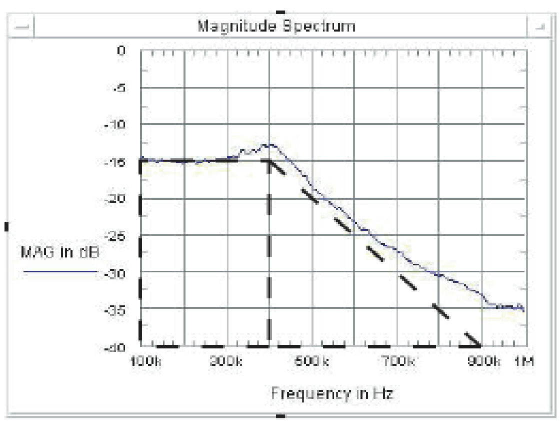

FIGURE 3
SPECTRUM ANALYZER DISPLAY OF A RANDOM NOISE SIGNAL WITH SUPERIMPOSED APPROXIMATE GEOMETRY FOR CALCULATING THE AREA.

II. Autocorrelation of a Random Process

The objective of this experiment is to increase student understanding of the autocorrelation of a random process. The random process modeled in this laboratory is a sinusoid with a random phase $r(t)=A_C cos(2\ \ f_c t +\ \ )$ where   is uniformly distributed between *0* and *2*   radians. The autocorrelation of this random process is computed using the TIMS configuration shown in Figure 4.

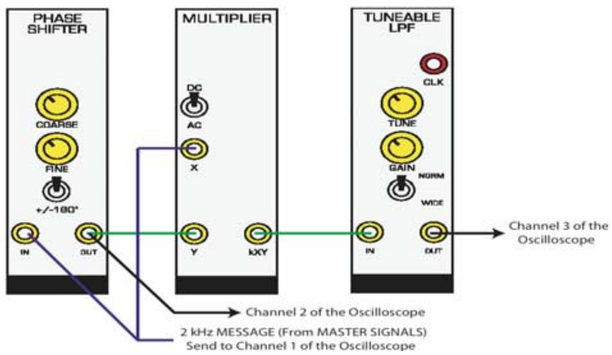

FIGURE 4

TIMS CONFIGURATION FOR COMPUTING THE AUTOCORRELATION OF A RANDOM PROCESS.

The output of the LPF is observed on the oscilloscope and used to compute the value of the autocorrelation for a particular value of the phase. The students measure the autocorrelation for several values of the phase and compare the results to the theoretical results as shown in Figure 5. This experiment gives a physical meaning to autocorrelation, enables the student to "see" orthogonal signals and also gives a physical interpretation of integration in the form of a low pass filter.

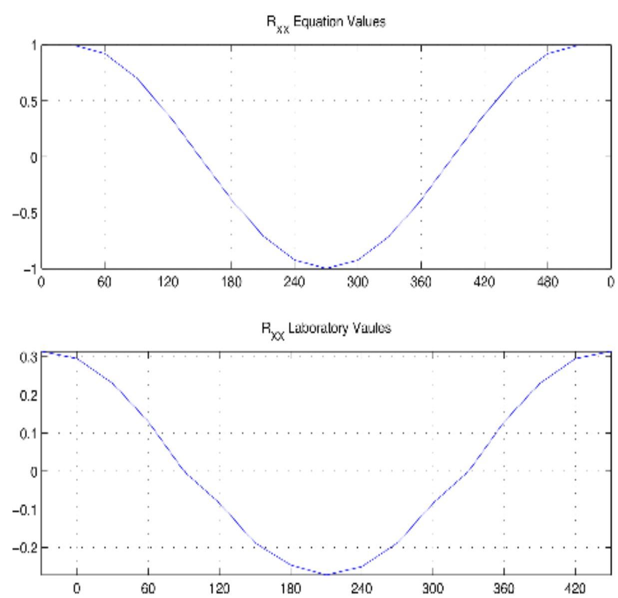

FIGURE 5

THEORETICAL AND MEASURED AUTOCORRELATION OF A SINUSOIDAL RANDOM PROCESS.

Conclusions

Descriptions of two laboratory experiments used in an undergraduate course in probability and random processes are given. Protocols for four experiments are available from the first author's website. The effectiveness of this laboratory in increasing student outcomes will be studied during the Fall 2004 semester.

Bibliography

[1] S. Srinivasan, L. C. Pérez, R. D. Palmer, M. F. Anderson, A. J. Boye, "An Integrated Signals and Systems Laboratory at the University of Nebraska: Laboratory Philosophy and Study Design", *Proceedings of the 2003 ASEE Annual Conference and Exposition*, Nashville, TN., June 22-25, 2003.

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