Work in Progress: Higher-Level-Learning Enhancements to Online Assignments in an Electrical Engineering Linear Systems Course

Chen Jia and Steve Warren

Kansas State University, Electrical & Computer Engineering, 2061 Rathbone Hall, Manhattan, KS 66506 USA
Phone: (785) 532–5600, Fax: (785) 532–1188, Email: jiachen@ksu.edu and swarren@ksu.edu

Abstract – **Online assignments with mathematical analyses often replicate the handwritten problem-solving process. This paper addresses work-in-progress enhancements to online linear-systems modules that move past procedural solutions toward visualizations and exercises that promote deeper thinking. Current enhancements address (1) plotting additions to zero-input response and unit-impulse response help files and (2) a new Fourier series module that targets coefficient comparisons rather than calculations. The time-domain enhancements focus on the visualization of signals that are solutions to the system equations, whereas the Fourier series additions focus on the roles that the coefficients play in determining signal shape. Upon completion of this enhanced module set, data from in-class examinations and out-of-class teaching/learning interviews will be compared to similar data from prior course offerings in an attempt to quantify the effect of these higher-level, conceptual additions on learning.**

Index Terms – **Fourier series, higher level learning, linear systems, and online homework**

I. MOTIVATION

Linear Systems is a course taken by Kansas State University (KSU) Electrical and Computer Engineering (ECE) seniors. It covers time- and frequency-domain concepts germane to signals and systems. Linear systems is often perceived as difficult because it relies on an array of mathematical constructs and procedures that are assumed to be embedded in the students working knowledge. Since Spring 2004, KSU ECE has employed online homework modules in linear systems [1, 2] that create problems in several domains, including zero-input response, unit-impulse response, and Fourier series –topics relevant to this paper. These modules were written to (a) provide a means to quickly generate and grade problems customized to each student, (b) populate databases that can be used to track concept retention from earlier math courses that use similar module/database technologies [3], and (c) increase student interest through the use of a multimedia interface.

From previous exam/project performance and lessons learned from one-on-one teaching/learning interviews [4, 5], it is clear that students still struggle in areas addressed by these modules. For example, students that solve *time-domain* differential equations defined by n^{th}–order systems (e.g., to obtain the system zero-input response or unit-impulse response) often do not have a sense of whether their answers are correct. One fundamental problem appears to be a typical student's inability to visualize the curve shape represented by the time-domain equation. Another issue is the tie between the initial conditions used to find the response and their manifestation in the corresponding curve.

Another area of struggle relates to the role that frequency-domain Fourier series coefficients play in the character and shape of the corresponding time-domain signal. A student will confidently perform the mathematical recipe needed to calculate those coefficients but have little sense of the effects that simple coefficient changes induce on the respective time-domain signals.

The next section describes upgrades to the online linear systems modules that are intended to address these time- and frequency-domain misunderstandings.

II. METHODS

The primary goal of this effort is to enhance the online tools so as to guide higher-level thinking without making the online experiences cluttered or complicated. A second motivation is to add module features that help students visualize concepts or think more deeply about them without requiring an undue amount of new calculations. The authors are implementing these new features into the modules with a goal to repeat similar exam-based and interview-based assessments as were used in Spring 2010 [4]. The hypothesis for this work is that the students will demonstrate a measurable increase in conceptual understanding based on these additions. The additions themselves are described in the two sections below.

A. Time-Domain Signals

The former instantiations of the zero-input and unit-impulse response modules required homework-like solutions, where mathematical answers were entered into text fields [2]. Updates to these modules include plotting facilities in the help files that graphically depict the solution for the system response, note the initial conditions on the curve, and mark features such as bounding curves and zero crossing. An example zero-input response for an underdamped system is plotted in Fig. 1. Note that the solid red line representing the response is a dashed line for $t < 0$. Bounding exponentials are marked as gray dashed lines. Zero crossings are marked with red circles, and the initial condition and slope are represented by the dashed green line. Colors of the expressions in the text above the plot are matched to the colors of the corresponding curves/marks.

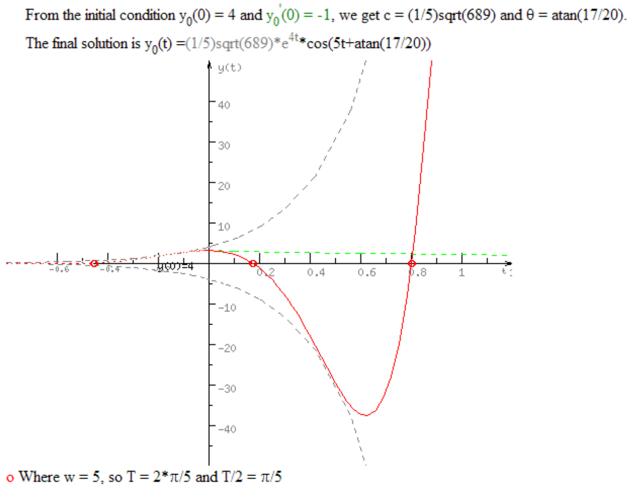

FIGURE 1
OUTPUT SIGNAL VISUALIZATION FOR A ZERO-INPUT RESPONSE PROBLEM

B. Frequency-Domain Coefficients

In the new conceptual Fourier series module, an original signal is generated, such as the one in Fig. 2. The module then provides an altered version of the signal, like the one in Fig. 3. It asks the student questions about the changes in the Fourier series coefficients required to perform such an alteration. Four such alterations are presented, and both trigonometric Fourier series and compact trigonometric Fourier series are addressed. These questions seek to improve a student's understanding of the role of Fourier series coefficients (i.e., improve their conceptual, higher-level thinking) without needing complex calculations.

For example, a trigonometric Fourier series

$$f_{TFS}(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(2\pi n f_0 t) + b_n \sin(2\pi n f_0 t)$$

may describe the signal, $f(t)$, depicted in Fig. 2, where a_0 is the waveform baseline, and a_n and b_n are the basis function amplitudes. Typical alterations to $f(t)$ include the following, where a student is tasked to identify the corresponding coefficient changes:

1. An amplitude change, which will change a_0 (if a_0 is non-zero), a_n, and b_n.
2. A flip about the vertical axis (i.e., time inversion), which will negate the b_n values.
3. A baseline and/or period change that affects a_0 and ω_0.
4. A time delay that affects the phase in the compact Fourier series representation.

For the signals in Figs. 2 and 3, the answers are $\omega_0' = \omega_0$, $a_0' = a_0$*(-2) +0, $a_n' = a_n$*(-2), and $b_n' = b_n * (-2)$.

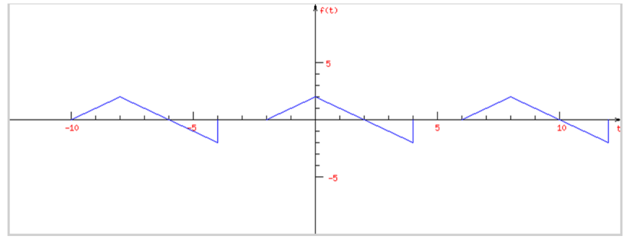

FIGURE 2
EXAMPLE REFERENCE SIGNAL FOR THE NEW FOURIER SERIES MODULE

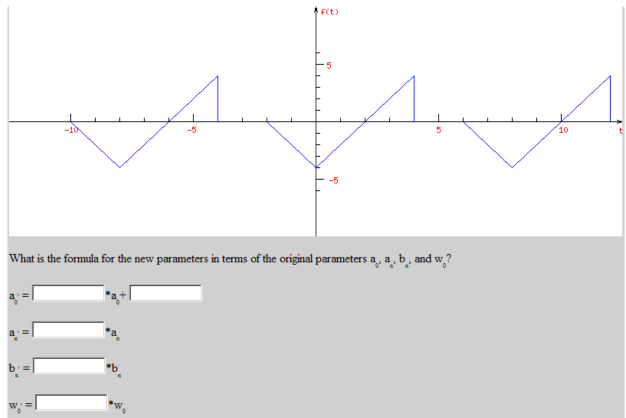

FIGURE 3
EXAMPLE COMPARISON SIGNAL AND ANSWER ENTRY FIELDS

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation *Research and Evaluation on Education in Science and Engineering (REESE)* Program under grant DRL–0816207. Opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF. Studies involving human subjects were conducted with the oversight of the KSU Human Studies Board under protocol #4691.

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