DEVELOPMENT OF VISUALIZATION TOOLS FOR RESPONSE OF 1ST AND 2ND ORDER DYNAMIC SYSTEMS

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Abstract

Students often enter a Dynamic Systems course with no real background or exposure to many of the concepts used to define "non-static" systems. The material is often a significant departure from the previous material covered, and the vernacular/terminology is very new and unfamiliar to the students. Nomenclature and concepts such as poles, zeros, s-plane, and others cause some confusion for the students.

In order to help the students further explore these new concepts and ideas and overcome some of the issues related to this departure in material, several MATLAB and LabVIEW graphical user interfaces (GUIs) have been developed. GUIs related to response of first and second order systems due to a variety of different input conditions have been developed. The GUIs present data in a form so that students can immediately see the effects of changing system parameters as they relate to pole locations in the s-plane, time response and settling time, and complex frequency response characteristics. The GUIs are presented along with student survey assessment on the usefulness of the new software tools.

I. Introduction

Mechanical Engineering students take a wide variety of different courses in the solids and thermofluids fields. In the area of solids, courses such as statics, strength of materials, etc. generally revolve around simple concepts of static strength with some material on fatigue but with no real description as to how those dynamic loads are created. In fact, the majority of a student's curriculum may center on these basic static concepts with little exposure to real response of dynamic systems. Even courses in dynamics generally focus only on the subject of rigid body dynamics. The fundamental concepts of frequencies, damping, poles/zeros, etc. are

not addressed until either a Dynamic Systems course taught at the Junior or Senior level or a sequence of Vibrations and Controls courses. However, depending on the particular curriculum of an individual program, many times only one Dynamic Systems course is available along with elective courses in Vibrations and/or Controls. Suffice it to say that the engineering student enters into a course such as Dynamic Systems with very little exposure (if any at all) in vernacular typically used for this material.

The beginning of a Dynamic Systems course finds the student perplexed and confused concerning basic topics. Of course, the student has already seen portions of this basic material in math related courses such as Ordinary Differential Equations, but it is likely that the student has no recollection of that material nor were there any "practical" examples that might have forced the student to remember any of that material. In teaching a Dynamic Systems course, basic concepts of complex numbers (real and imaginary), relationships of exponentials and sines/cosines, solutions of 1st and 2nd order differential equations, Laplace transforms, Fourier Series, etc. are expected to be firmly planted in the student's skill sets. Often, however, these courses were taken semesters or even years prior and the reality is that the students simply do not remember any of that former material.

In order to circumvent some of these issues, a series of MATLAB, Simulink and LabVIEW based modules with Graphical User Interfaces (GUIs) have been developed to address various aspects of 1st and 2nd order systems [1,2]. The intent of these modules is to have the students control the pace of knowledge obtained to provide a thorough comprehension throughout the process [3]. In addition, it has been shown that multimedia content generally enhances student retention and interest [4,5,6] and that engineers are primarily visual learners [7]. However, the primary mode of presentation must include additional traditional mechanisms [8] to properly convey material.

Primarily two different modules are described in this paper. One addresses 1st order system response and another addresses 2nd order system response. The GUIs developed are described in the following sections. These have been developed using MATLAB, Simulink and LabVIEW.

II. 1st Order System Characterization

First order systems are common in many mechanical engineering dynamic systems problems, as well as in chemical, electrical and other fields. Two different first order systems are described herein – one demonstrates the traditional time response of a first order system, and the second describes the frequency response of a first order system such as that seen in an RC circuit (ie, low pass filter).

The step response of a first order system is often studied in many fields since it is a common response phenomenon. A MATLAB GUI was developed for this work. The RC Circuit Step Response GUI was designed to be used to assist in a student's understanding of the response characteristics of a first order system. This GUI allows the user to vary the resistance and capacitance and view the resulting time response due to a unit step input. The GUI is shown in Figure 1. Along with the GUI interface, the input parameter selection and output information computed for the first order system are shown. The input parameters can be selected either with

manual entry for specific values or using slider bars for varying the resistance and capacitance values. The output of the time constant and settling time are updated as the user selects various values for the RC circuit.
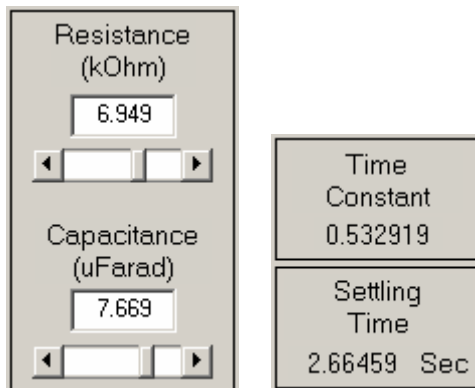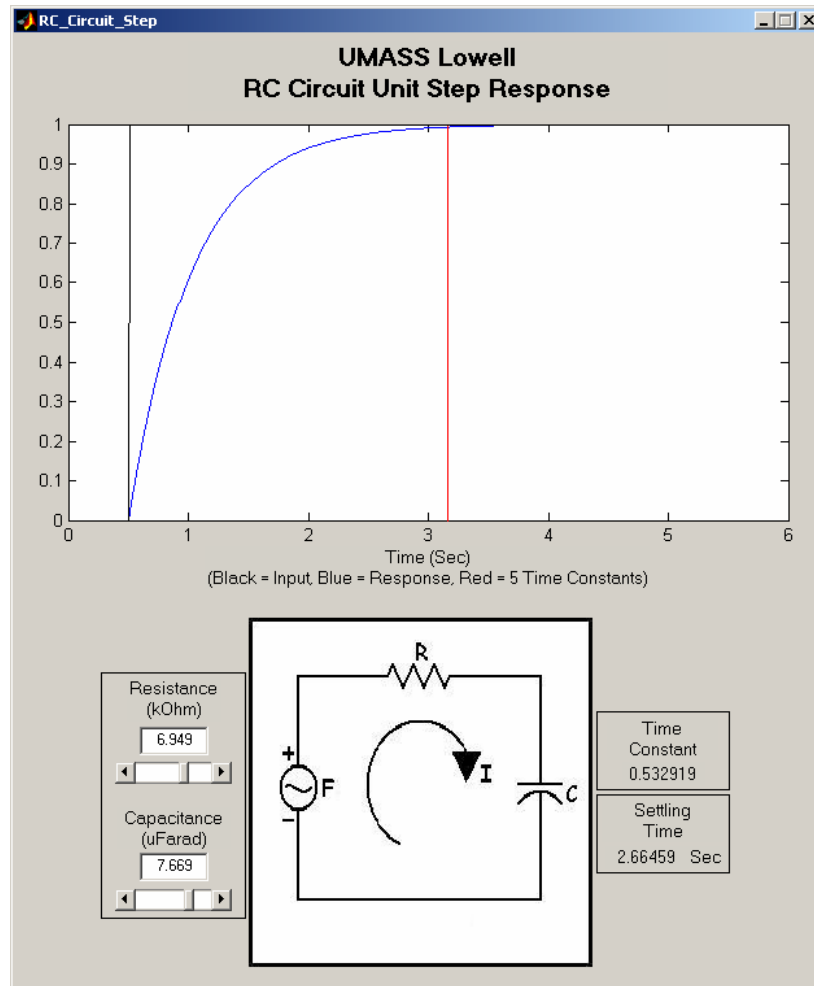

Figure 1 – MATLAB 1st Order System Characterization – Time Response

Another common use of a first order RC circuit for mechanical engineering applications is in the area of measurements and the use of a low pass filter. Since this application is useful to

mechanical engineers that are often unfamiliar with electrical applications of filtering, a separate MATLAB GUI was developed for students to explore the cutoff frequency and signal attenuation as a function of frequency/cutoff ratio.

This MATLAB GUI allows the user to vary the time constant and excitation frequency and view the resulting time response attenuation and phase shift. The GUI is shown in Figure 2. The input parameters can be selected either with manual entry for specific values or controlled by slider bars. The output amplitude and phase lag are reported.
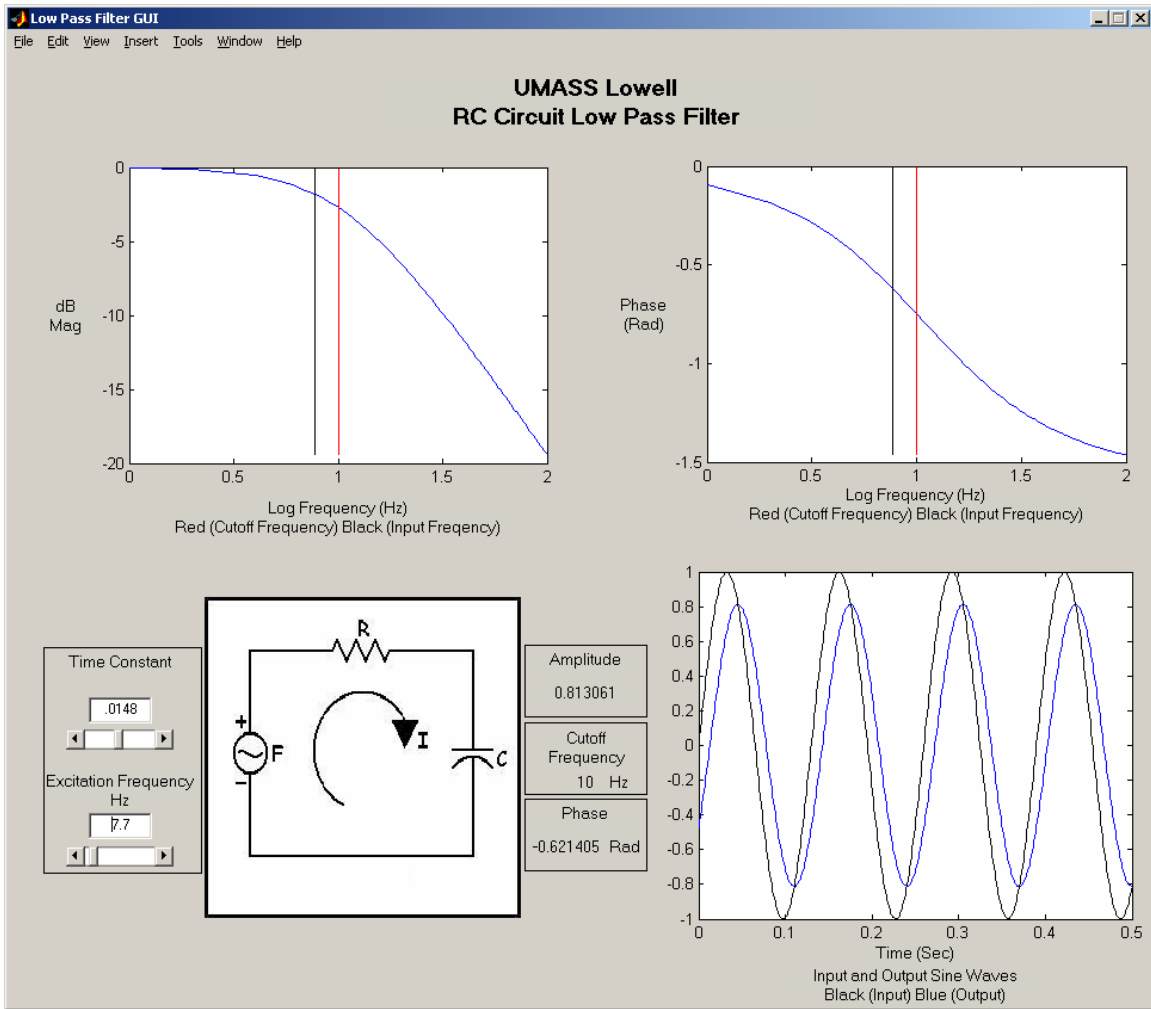

Figure 2 – MATLAB 1st Order System Characterization – Low Pass Filtering

In addition to the MATLAB GUI, another GUI is available using LabVIEW and is shown in Figure 3. This LabVIEW GUI varies slightly from the MATLAB GUI. The user selects the resistance and capacitance which results in a reported time constant τ and a reported cutoff frequency for the low pass filter. The student can select these parameters, as well as the input frequency to be filtered. The filtering effects on the signal magnitude and phase are reported to the user. The frequency response characteristics of the filter (magnitude and phase) are plotted along with the time response of the signal, both before and after filtering. This clearly shows the magnitude and phase distortion due to the filter effects.
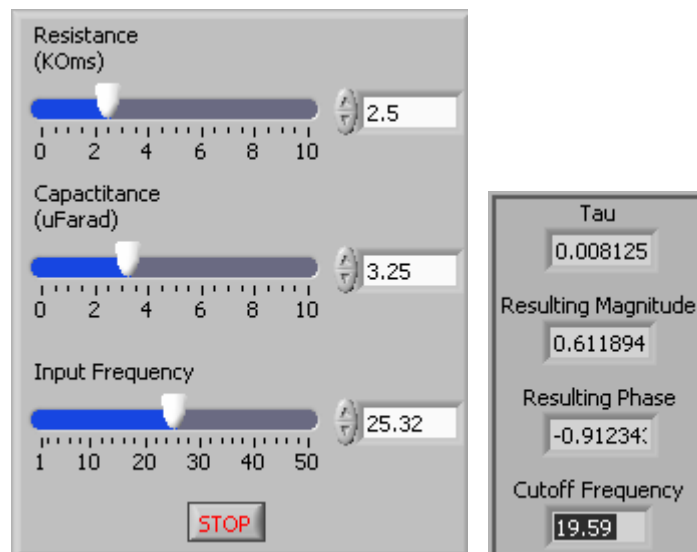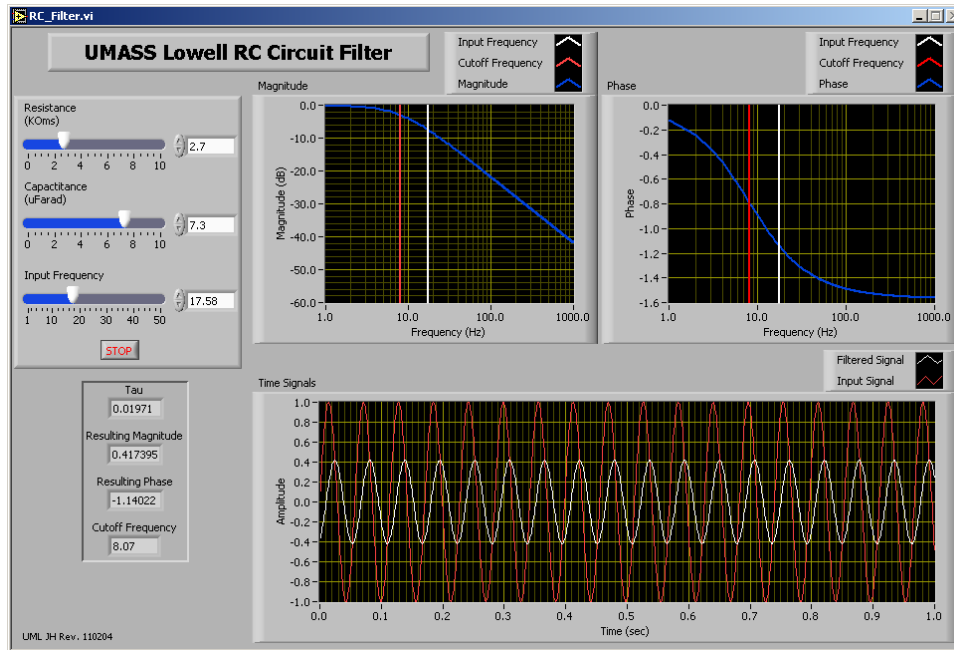

Figure 3 – LabVIEW 1st Order System Characterization

III. 2nd Order System Characterization

Second order systems are also abundant in engineering and form a cornerstone of knowledge. Several different MATLAB and LabVIEW GUIs were developed on these systems. Response of a second order system is generally studied as a result of a step function, impulse or initial conditions on the system. Three different MATLAB GUIs were developed for each of these; only the initial displacement response is shown here as the three GUIs are similar. The MATLAB GUI is shown in Figure 4.

The student is allowed to enter the mass, damping and stiffness for a single degree of freedom second order system (with manual entry for specific values or using slider bars) to see the effects of changing parameters. The GUI reports the natural frequency, damping ratio and the critical damping. The plotted characteristics of the GUI include time, frequency and s-plane information. This enables the student to quickly see the inter-relationship of each of these important forms for presenting the data. Students often do not clearly understand the inter-relationship between the three different modes of presentation and the GUI helps to solidify this critical link.
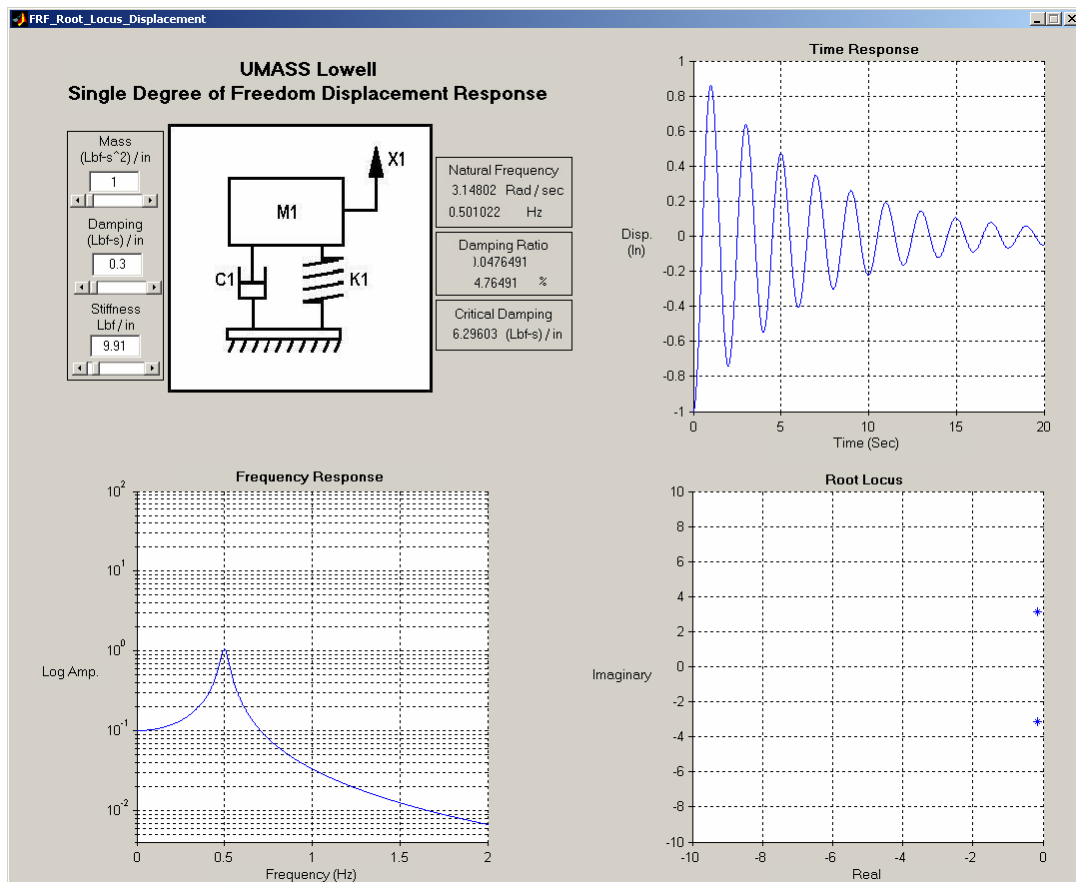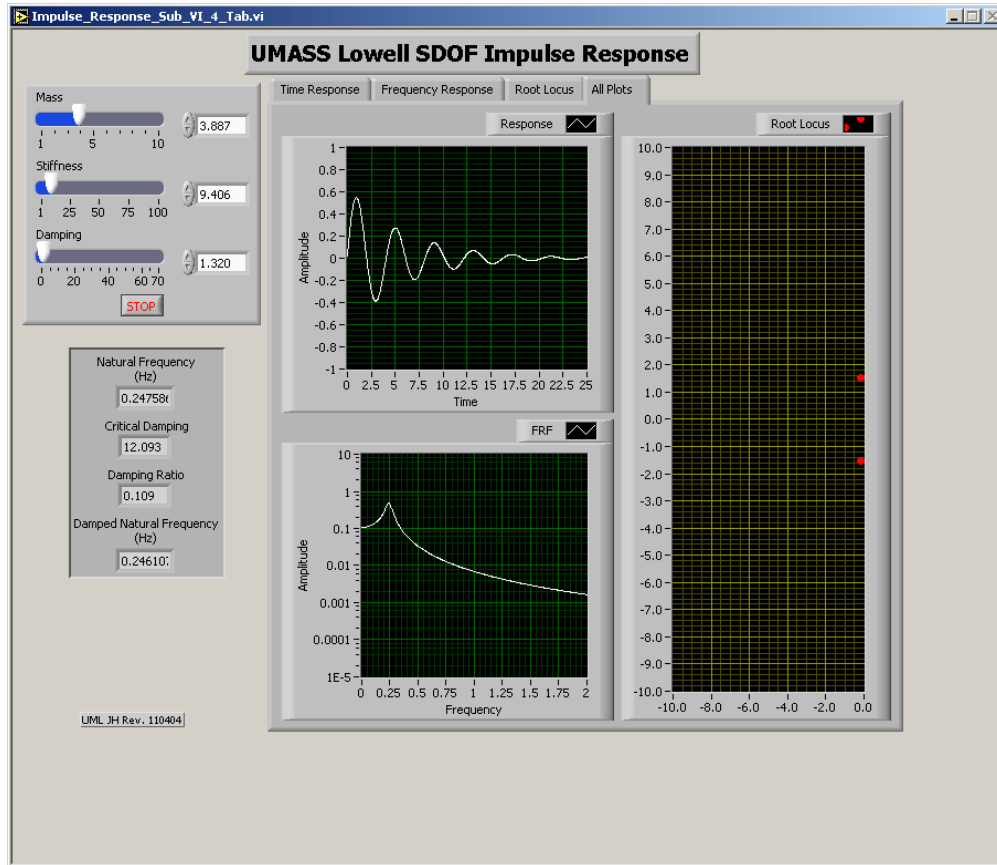

Figure 4 – MATLAB 2nd Order System Characterization

A second GUI using LabVIEW is shown in Figure 5. Again the students can enter mass, damping and stiffness, and the natural frequency, damping, etc are reported. The LabVIEW GUI allows the student to select a particular plot form (time response, frequency response, root locus) or to display all the forms simultaneously as shown in the figure. Again this format of presentation helps the students to solidify this critical link between the different forms for presenting this data.
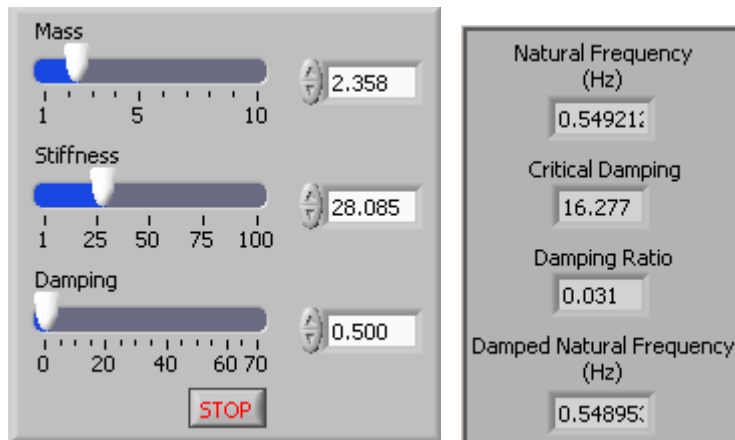
Figure 5 – LabVIEW 2nd Order System Characterization

IV. Student Assessment of GUIs

The 1st and 2nd order system response GUIs have been used in classes such as Ordinary Differential Equations, Mechanical Engineering Laboratory and Dynamic Systems. Upon being surveyed as to their overall understanding of this material, 45% of the students responded that they felt comfortable regarding the development of mathematical material related to 1st and 2nd order systems and 35% felt that they were partly comfortable with the material. Approximately the same percentages applied to the student's belief that the classroom lectures were sufficient to fully explain the material.

However, even with those positive percentages, well over 75% of the students strongly felt that the GUIs helped to further their understanding of filtering characteristics, effects of damping on poles location and time response, and effects of mass-damping-stiffness on system characteristics; another 15% of the students felt that the GUIs somewhat enhanced their overall understanding of the material. Clearly there is a strong indication that the GUIs reinforced the concepts of 1st and 2nd order systems as evidenced by 90% of the students indicating that there was a distinct benefit in using the GUIs to better appreciate this material.

When queried if the material was understood well enough that the use of the GUI was not needed, over 50% felt that the GUI was essential in their understanding of the material; close to 25% felt that it partly augmented their understanding.

Clearly, the students felt that the GUIs helped them to visualize the mathematical solutions with much greater ease and allowed a much deeper understanding of the underlying concepts.

V. Summary

The response of first and second order systems is critical in many engineering applications. Unfortunately students often fail to truly comprehend this material as part of a differential equations course. This is primarily due to lack of motivation to retain the information since they feel no compelling reason to do so. Also, the material may have been presented in a fairly bland environment and the material is catalogued away with other "unimportant information" – from the student's perspective.

A new approach has been employed to allow the students to use a variety of different software Graphical User Interfaces (GUIs) using either MATLAB or LabVIEW to further complement the lecture material presented in class. The students can use the GUIs to assist themselves in gaining a more thorough understanding and appreciation of the response of these types of systems which involve a multitude of different presentation forms – time, frequency and root locus approach. Student response was very strong concerning the need of the GUI to help foster a deeper understanding of this material – even when they felt they appreciated the math presented in class.

VI. Acknowledgement

VI   References

1   Higley,K.A., Marianno,C.M., "Making Engineering Education Fun", Journal of Engineering Education, Vol 90, No. 1, pp105-107, January 2001
2   Knight,C.V., McDonald,G.H., "Modernization of a Mechanical Engineering Laboratory using Data Acquisition with LABVIEW", ASEE 2003 Session 2266
3   McConnaughay,K., Welsford,I., Stabenau,E., "Inquiry, Investigation, and Integration in Undergraduate Science Curricula", Council on Undergraduate Research Quartley, pp14-18, September 1999
4   Mantei,E.J., "Using Internet Class Notes and Power Point in the Physical Geology Lecture – Comparing the Success of Computer Technology with Traditional Teaching Techniques", Journal of College Science teaching, pp301-305, April 2000
5   Regan,M., Sheppard,S., "Interactive Multimedia Courseware and Hands-On Learning Experience: An Assessment Study", Journal of Engineering Education, pp123-131, Apr 1996
6   Riggs,B., Poli,C., Woolf,B., "A Multimedia Application for Teaching Design for Manufacturing", pp63-69, January 1998
7   Serow,R., Zorowski,C., "Diffusion of Instructional Innovations in Engineering Education", North Carolina State University, www.suceednow.org
8   Kolb,D., "Experiential Learning", Prentice Hall, Englewood Cliffs, NJ 1984

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