

AN INTERWOVEN MULTISEMESTER DYNAMIC SYSTEMS PROJECT TO INTEGRATE STEM MATERIAL

Dr. Peter Avitabile, Associate Professor, Mechanical Engineering Department

Dr. Stephen Pennell, Professor, Mathematics Department

Dr. John R. White, Professor, Chemical Engineering Department

University of Massachusetts Lowell

One University Avenue

Lowell, Massachusetts USA

Peter_Avitabile@uml.edu

Abstract

Students generally do not understand how basic STEM (Science, Technology, Engineering and Mathematics) material fits into all of their engineering courses. Because they have no clear-cut reason to embrace these concepts, the students hit the “reset button” after each and every course. This often comes back to haunt the students in subsequent upper level classes which require a firm understanding of this material.

A new multisemester interwoven dynamic systems project has been initiated to better integrate the material from differential equations, mathematical methods, laboratory measurements and dynamic systems across several semesters/courses so that the students can better understand the relationship of basic STEM material to an ongoing problem. This paper highlights the overall concept underlying the new approach. A description of the project and modules under development is given.

Introduction (or Motivation)

Many students do not understand the need for basic STEM (Science, Technology, Engineering and Mathematics) material that is critical to the solution of engineering problems. The knowledge required to solve problems related to dynamic systems is taught in several different courses, which makes the material appear disjointed from a student’s perspective. The overall course sequence and requirement of pre-requisite material naturally tends to make the inexperienced student think that material is disjointed – each course presents material as a set of tools that, from the student’s perspective, has no relationship whatsoever to material presented later on in the educational curriculum. Students naturally tend to hit the “reset button” after each

and every course since there is no apparent reason to want to actively retain required information. All professors encounter this problem as depicted in Figure 1.

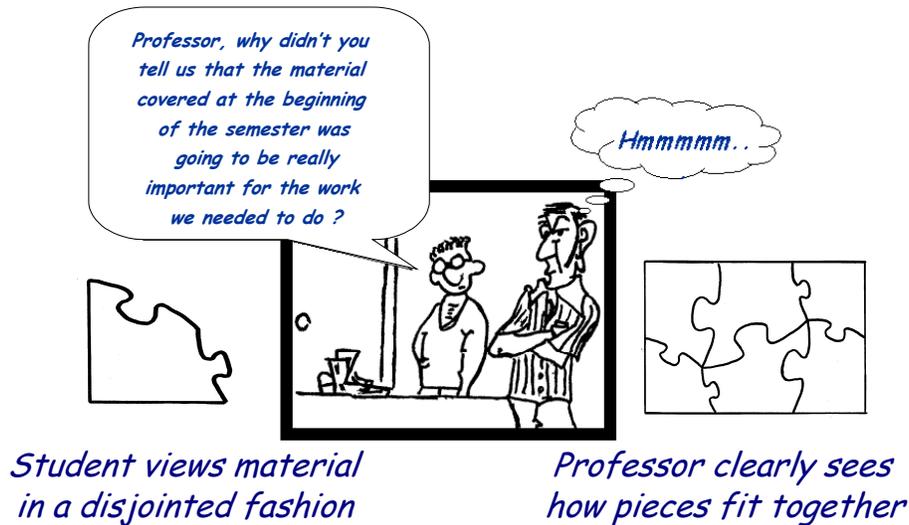


Figure 1 – Professor vs. Student View of Material Presented

In order for STEM material to become an integral part of the student's learning process throughout their entire educational and professional careers, the students must, in essence, "live the material" every day and in every course [1-5]. To make this happen, one important step is to stop presenting information in a disjointed fashion.

Engineering problems are never solved by "looking up answers at the back of the book". However, this is the exact way many engineering courses are taught. Students feel that they can push the "reset button" after each class since they do not see the integration of all the material until late in their undergraduate career through the capstone experience. At this point, they realize that most of that earlier material *really was relevant*.

Basic Concepts (or Goals and Objectives)

Different approaches (i.e., ODE, Laplace, Fourier, Numerical Methods, etc) can be used to solve the same problem. Unfortunately, these are covered in different courses and often the inter-relationship is not emphasized! What typically happens is that the students don't see the connections among these methods because each technique is applied to a different problem [2]. In order to help the students understand the application of each technique, the same generic problem needs to be incorporated into each course to show the application of each technique and the resulting similarities and differences. Therefore, the concept underlying this project is to develop a project which spans several semesters and courses to interweave the related STEM material in a coherent fashion, strongly emphasizing the interrelationship between course materials that the students currently perceive as unrelated and disjointed.

The simple RC circuit and simple single degree of freedom mass-spring-dashpot system are generic to all engineering problems. These provide an excellent starting point for building a base of knowledge. A concept schematic showing various pieces of interrelated material is presented in Figure 2. The figure shows various aspects of different approaches to solve the dynamic response of a simple cantilever beam. All the material shown is important for solving dynamic system problems.

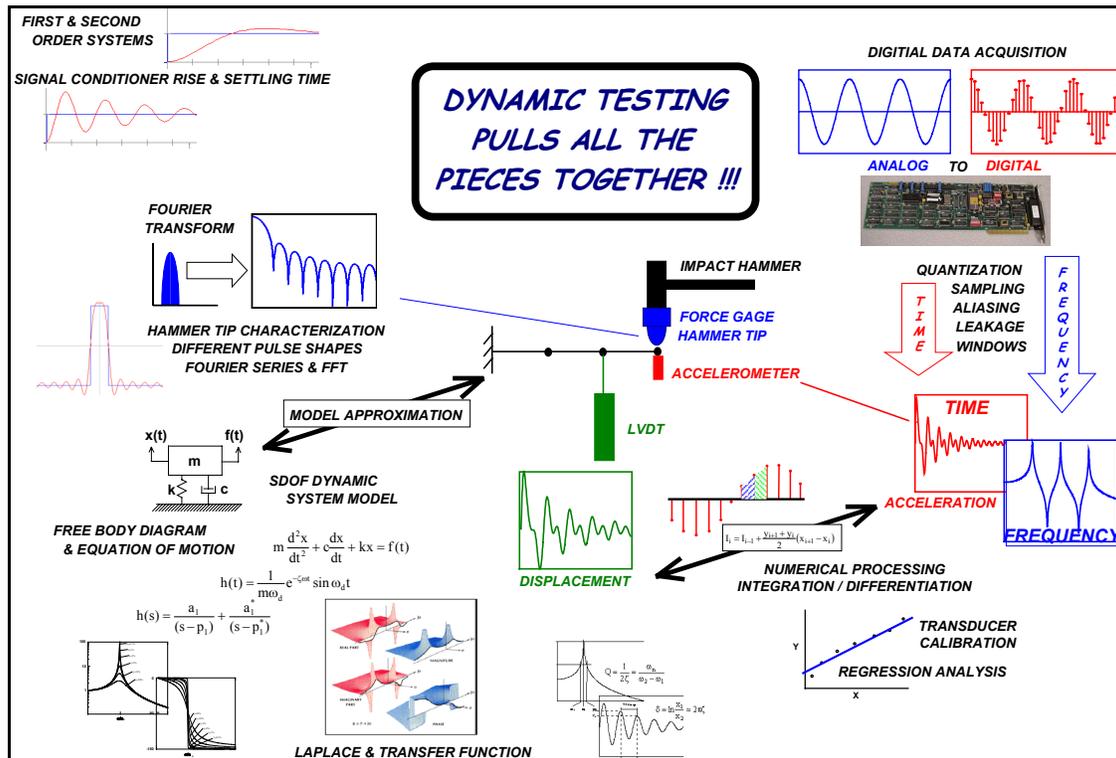


Figure 2 – Concept Schematic of Interwoven Material

Structured and designed correctly, the interwoven, multi-semester problem has numerous features of differential equations, Fourier/Laplace transforms, and numerical processing of both time and frequency data (which can consist of both simulated analytical data and actual measured experimental data). The lab component of this problem can introduce instrumentation/signal conditioning, calibration, analog and digital data acquisition systems, time and frequency data (FFT), impulse response/frequency response, rise time and settling time in both instrumentation and actual structural systems, as well as considerations of transducer design to measure the desired characteristics of a dynamic system.

The inclusion of the laboratory component immediately adds another dimension to the problem. While the evaluation of “well-behaved” analytical data is the cornerstone of the student’s understanding of how to process data and develop analytical models, experimental issues pertaining to “real” data quickly illustrate the need to employ all the STEM tools [6]. The STEM material related to the problem posed can be easily converted to any of the specific engineering disciplines such as electrical systems, thermal systems, flow systems, etc.

Interwoven Project Concept

The efforts of this work are directed towards the development of a new, creative approach to address student understanding of related material in different courses through the use of a multi-semester interwoven project to reinforce basic STEM material critical to solving dynamic systems problems. A strong laboratory component with multimedia and hands-on application of STEM material will reinforce theoretical concepts.

Technical Materials Developed

In order to create the multise semester integrated approach, a series of inter-related tutorials covering a variety of pertinent materials was created to address first and second order systems. These materials are intended to address mechanical systems from an analytical standpoint as well as the measurement of those analytical systems which then introduce electrical signal conditioning/measurement issues that also involve first and second order systems. These materials can be roughly broken down as:

Theoretical Aspects of First and Second Order Systems

First Order Systems – Modeling Step Response with ODE and Block Diagram

Second Order Systems

Modeling Step, Impulse, and Initial Condition with ODE and Block Diagrams

Mathematical Modeling Considerations

- Fourier Series, Integration/Differentiation, Regression Analysis

Miscellaneous Materials

- Simulink and MATLAB Primer Materials

- Virtual Measurement Modeling Simulations

- Integration/Differentiation Considerations with Contaminated Data Sets

Many of the tutorials are supplemented with MATLAB and Simulink scripts as well as LabVIEW modules – both have been complemented with a Graphical User Interface (GUI). The GUI allows for the easy adjustment of various parameters so that the student can explore various system parameters and the effects on system response. A brief description of each of the tutorials is described below.

Theoretical Aspects of First and Second Order Systems – This covers a basic overview of the underlying information regarding the classical treatment of this material.

First Order Systems – Modeling Step Response with ODE and Block Diagrams

Response of First Order Systems – Step Response – Covers basic development of a model for a first order system. A MATLAB script with variable parameter selection via a GUI allows the user to explore parameters. A companion LabVIEW GUI model is also available.

Block Diagram Modeling of First Order Systems – Covers basic development of a model. A block diagram using Simulink is the end result of this tutorial. The user can vary parameters in Simulink to explore the effects of parameter variation.

Filtering using RC Circuits – Covers basic development of a first order system using the frequency domain rather than the time domain response approach. Concepts of time response, cutoff frequency, and roll-off are described and the filter effect on simple sine wave is introduced. A MATLAB script with variable parameter selection via a GUI is available.

Second Order Systems – Modeling Step, Impulse, and Initial Condition Responses with ODE and Block Diagrams

Response of Second Order Systems – Step, Impulse and Initial Conditions - Covers basic development of a model. A MATLAB script with variable parameter selection via a GUI allows the user to explore parameters.

Block Diagram Modeling of Second Order Systems – Covers basic development of a model. A block diagram using Simulink is the end result of this tutorial. A MATLAB script with variable parameter selection via a GUI allows the user to explore parameters.

Mathematical Modeling Considerations

Fourier Series Tutorial – Covers basic concepts of generating a set of Fourier series terms to approximate general waveforms. A Simulink script with variable Fourier series terms selection via a MATLAB GUI allows the user to explore the generation of arbitrary waveforms other than the specific values used in the tutorial.

Numerical Integration/Differentiation Tutorial – Covers basic concepts of general integration and differentiation of second order system response of displacement, velocity and acceleration. A MATLAB/Simulink GUI will be developed.

Regression Analysis Tutorial – Covers basic concepts of generation of least squares error fit of a set of data that consists of higher order effects but can be evaluated as piecewise linear over regimes of the data provided. A MATLAB GUI allows the user to easily select different data sets, model order, etc. and to view the effect on the computed analytical model that best describes the data.

Miscellaneous Materials

Measurement Problems – Covers basic concepts of measurements that can be obtained from second order systems; provides a Simulink GUI that allows the user to specify the second order analytical model and then introduce common measurement errors such as noise, bias error, drift, and offset on the analytical data for both acceleration and displacement measurements (commonly made with an accelerometer and LVDT, respectively). This tutorial pulls together all the pieces of the other tutorials and provides a virtual representation of an actual measurement system as encountered in the laboratory. This enables the students to provide some control on how “experimental parameters” contaminate their analytical model output and allows them to study the basic underlying effects in a very controlled fashion.

Analytical and Experimental Model Comparison – Allows the comparison of analytical predicted response with measured output response of the system. A MATLAB GUI allows the user to vary many parameters of the analytical model to estimate the best properties to approximate the system. The GUI allows the user to compensate for drift and offset as well as time compensation for event initiation. This tutorial helps the students to make estimates and comparisons of an analytical model and measured response with a simple GUI to control all of the parameters that affect the model.

Numerical Integration and Differentiation Comparison – Allows for the comparison of differentiated or integrated signals that are contaminated by noise, drift, bias and other measurement problems. A MATLAB GUI allows the user to vary many of the contaminating parameters that are added to the analytical model. The GUI allows the user to differentiate or integrate both the pure analytical and the “contaminated” signal to see the effects of distortion when processing data.

S-Plane 3D Frequency Response Function – Allows the user to explore the S-Plane through a GUI interface to see the effects of parameters on the system characteristics. A MATLAB GUI allows the user to explore the complex frequency response function (Re, Im, Mg, Ph) to see the effects of parameters on the system characteristics.

Simulink and MATLAB Primer Materials –

- Basic Tutorial on the Use of Simulink
- Importing and Exporting Data from MATLAB and Simulink to Excel
- Using State Space and Transfer Function Blocks in Simulink
- Modeling an Impulse in Simulink
- Use of the LTI Viewer and MUX Blocks in Simulink

Several of the MATLAB and Simulink GUI scripts are presented to illustrate some of the features available that assist the student in understanding the problems faced when actual measurements are acquired. The other tutorials also have either MATLAB or Simulink GUI scripts to allow the student to further explore the material in the tutorial.

Sample MATLAB and Simulink GUI Scripts

Several different MATLAB and Simulink GUI script files that are associated with some of the tutorial material are presented below; in addition, several similar LabVIEW modules also exist.

Single DOF Complex Frequency Response Function (FRF) Plot

The definition of a complex frequency response function requires students to clearly understand complex numbers as represented in the frequency domain. Sometimes there is confusion regarding this in the students minds. Differences in representation of magnitude/phase vs. real/imaginary are easy once a student becomes accustomed to this notation. A MATLAB GUI is provided that allows the students to specify the mass, damping and stiffness values of a single degree of freedom mechanical system; the values can be easily adjusted via keyboard entry or scroll bar. The frequency and damping of the system are reported along with complex frequency response plots. The MATLAB GUI is shown in Figure 3.

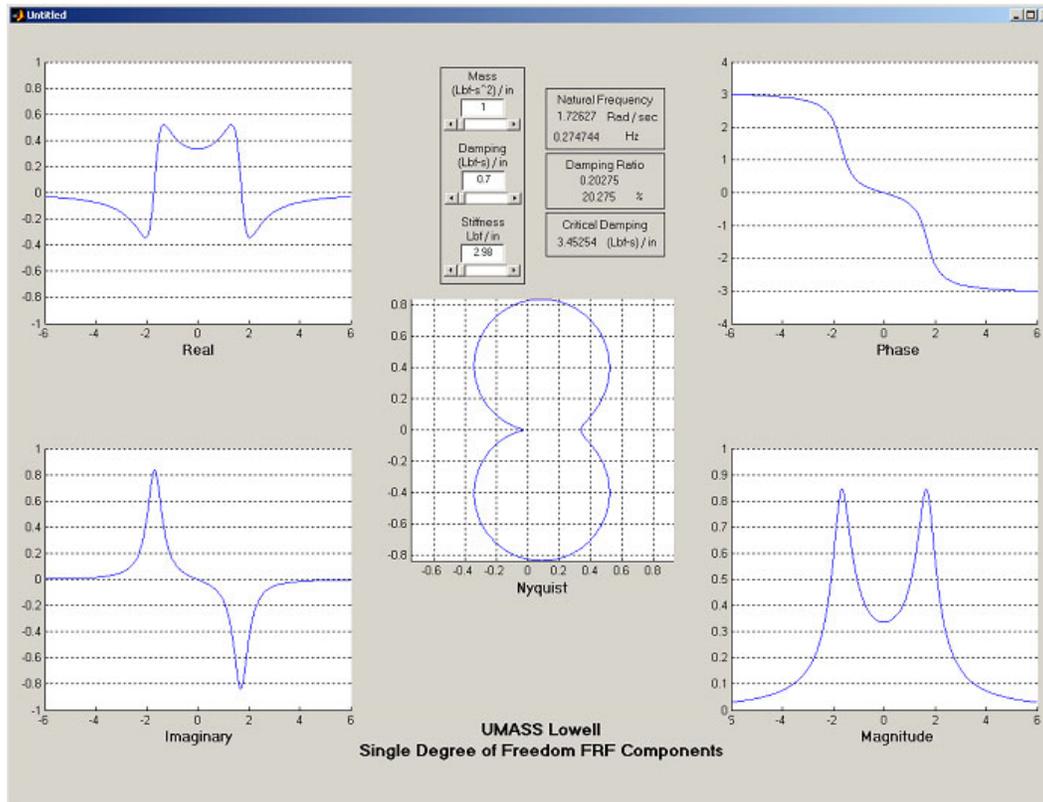


Figure 3 - Single DOF Complex FRF Plot GUI

Fourier Series Signal Generator

Fourier series are an important concept in the processing of time and frequency data. This mathematical concept is taught but the application is often missed by students until an upper level course or practical example presents itself. A Simulink GUI is provided to allow the student to specify the terms of the Fourier series and see the resulting time signal approximation. The user enters frequency, amplitude and phase components of a user defined signal to display the resulting signal; the values can be easily adjusted via keyboard entry or scroll bar. The user can also select sample signals such as square, triangle, etc and the pre-determined Fourier coefficients are applied to the user-defined signal. The time signal as well as the corresponding frequency component is displayed. The Simulink GUI is shown in Figure 4.

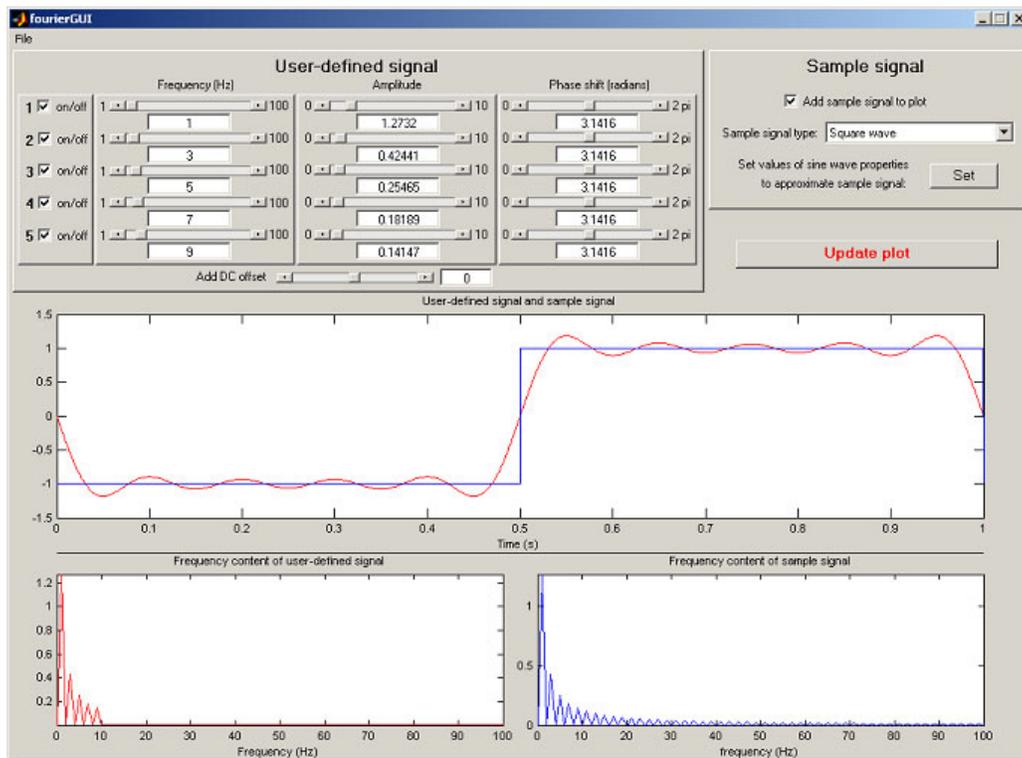


Figure 4 - Fourier Series Signal Generation GUI

In addition to the MATLAB/Simulink GUI, a companion LabVIEW GUI on Fourier Series is also available for student use. A LabVIEW tutorial is also available to guide the students to develop their own LabVIEW FFT GUI. This enables the students to comprehend the entire process of the time to frequency transformation process. The tutorial has the students develop a single sine wave and its FFT to clearly identify important aspects of this transformation process. The tutorial then leads the students through the addition of harmonic distortion components to the primary sine wave. This then becomes the prelude to the development of a square wave from the summation of Fourier coefficients. While the ultimate goal is to understand the time-frequency relationships and the FFT process, the tutorial reinforces these important concepts by having the students “doing” rather than “listening” [6] which has been shown to provide deeper learning and understanding of material.

First Order Low Pass Filter

The definition of a 1st order system is fairly straightforward. However, the frequency filter characteristics are not so obvious from a traditional time constant representation. Students (and sometimes engineers in industry) will remark that they didn't really realize just how much attenuation and phase shift really occurs in the low pass filter – 3 dB sounds very innocent until the actual plot characteristics are displayed. A very simple MATLAB GUI is provided that allows the students to specify the time constant and the excitation/source sinusoidal frequency; the values can be easily adjusted via keyboard entry or scroll bar values. The Bode plot (magnitude/phase) are displayed (with the cutoff frequency) along with the source and filtered time sinusoidal signal. A companion LabVIEW GUI is also available. The MATLAB GUI and LabVIEW GUI are shown in Figure 5.

Second Order System Step Response

The step response of a simple second order mass-spring-dashpot system is accomplished with the MATLAB GUI shown in Figure 6. A companion LabVIEW GUI is also available and shown in Figure 6 also. The students specify the mass, damping and stiffness values of a single degree of freedom mechanical system; the values can be easily adjusted via keyboard entry or scroll bar values. The frequency, damping, critical damping, etc. of the system are reported along with plots of the time response, frequency response and the root locus plot. As values are changed the plots update and the plot of the poles in the s-plane are easily observed.

Virtual Representation of an Actual Measurement System GUI

The interpretation of an actual measurement can be an overpowering experience to a novice student. There are numerous measurement issues that contaminate the expected response of the system that are related to instrumentation and transducer considerations. In order to assist the student in deciphering the data, an analytical model is developed and then “controlled” contamination signals are added to the known analytical response. Both acceleration and displacement measurements are included in this evaluation. These are typical measurements that are collected in the field and are generally contaminated by various factors. Since controlled effects are included in the simulation, the distortion is more easily identified. In this way, the students gain first hand experience as to how to interpret the information collected and gain a better understanding as to how to process the data.

The virtual representation of an actual measurement system is accomplished with the Simulink GUI shown in Figure 7. The students specify the mass, damping and stiffness values of a single degree of freedom mechanical system; the values can be easily adjusted via keyboard entry or scroll bar values. The sensitivity of a displacement measuring device and an accelerometer are included along with possible contamination of the measured signals due to noise, bias, drift and other problems. The contaminated signals of displacement and acceleration can then be saved/plotted and compared to other virtual measurements. This virtual measurement system is the complete representation of the entire measurement process and contains features from the other tutorials and simulations that are presented individually.

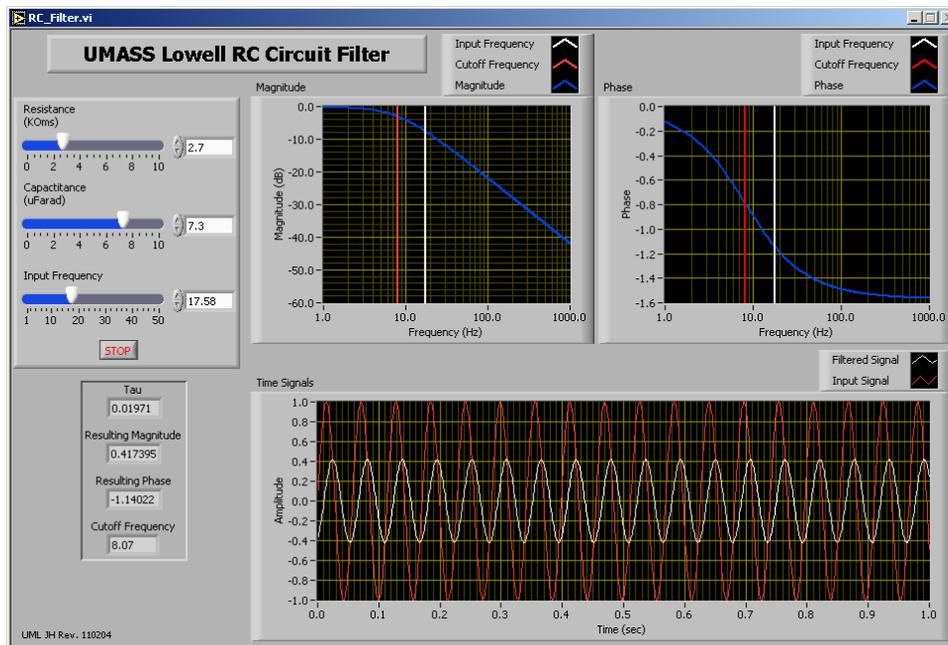
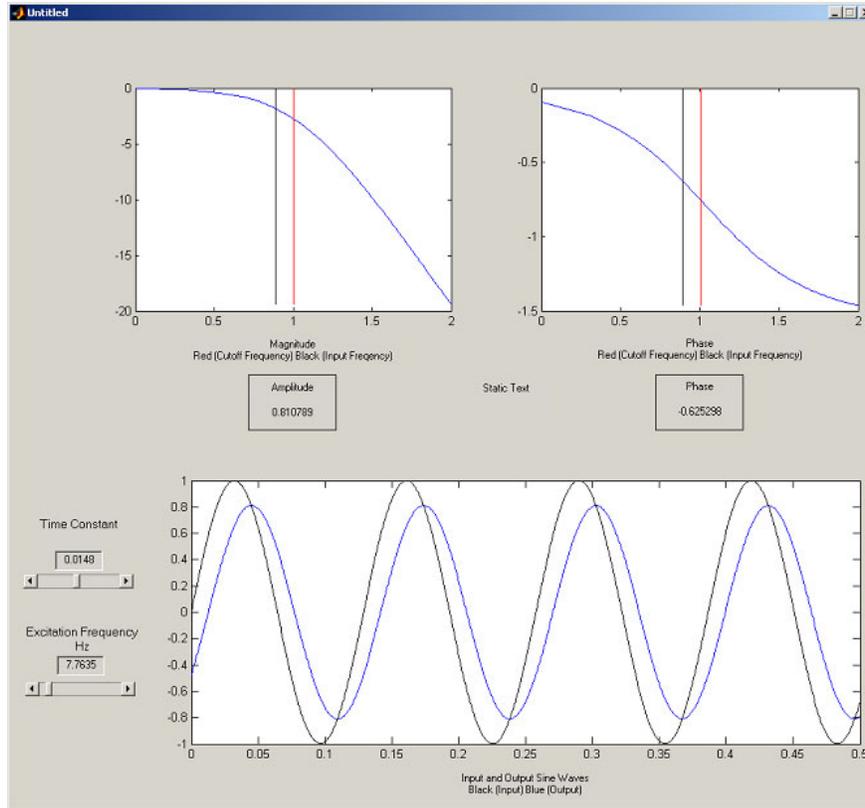


Figure 5 - First Order Low Pass Filter GUI - MATLAB (top) and LabVIEW (bottom)

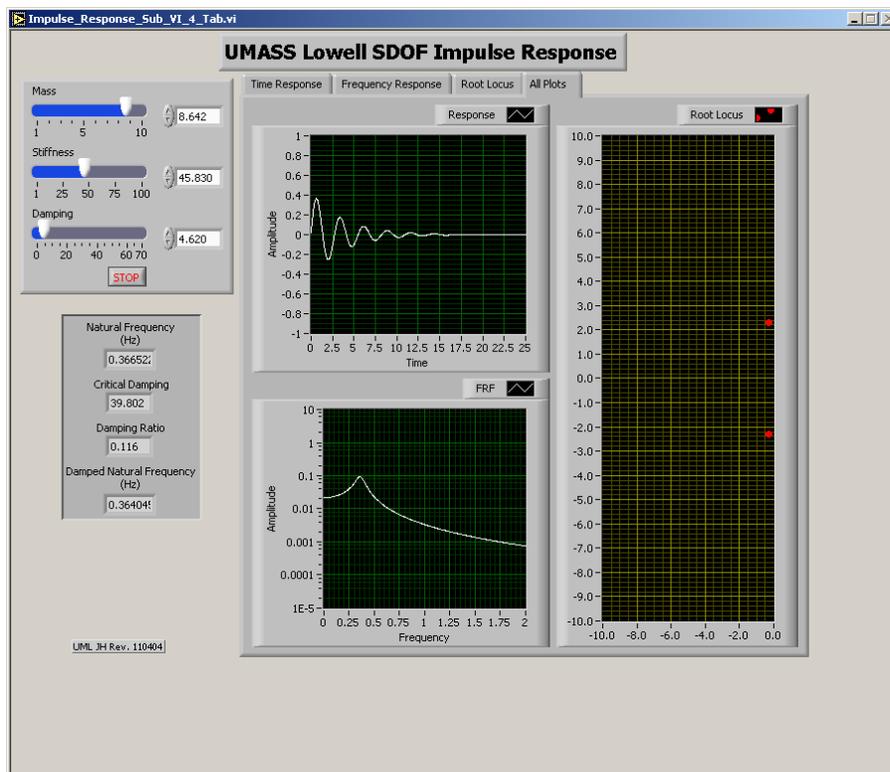
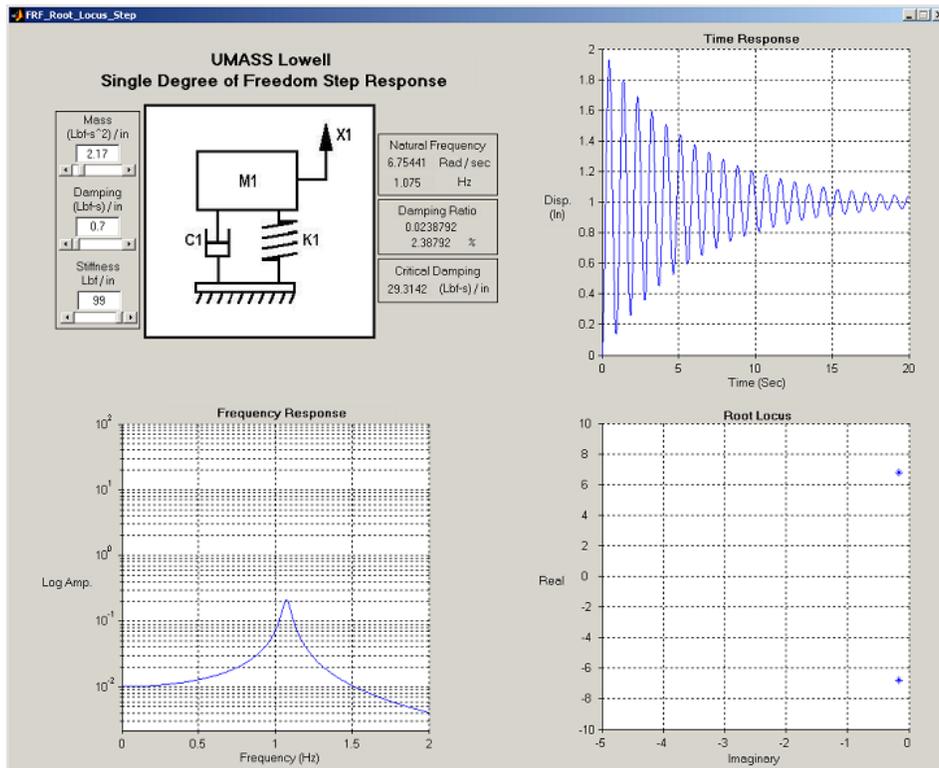


Figure 6 - Second Order System Step Response GUI - MATLAB (top) and LabVIEW (bottom)

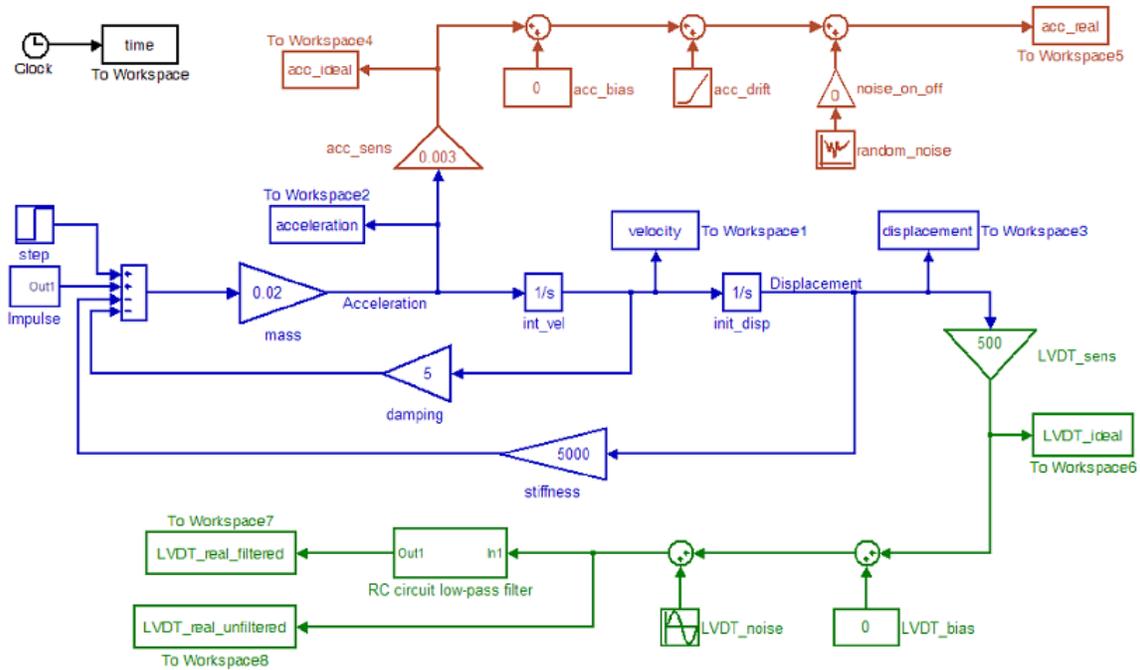
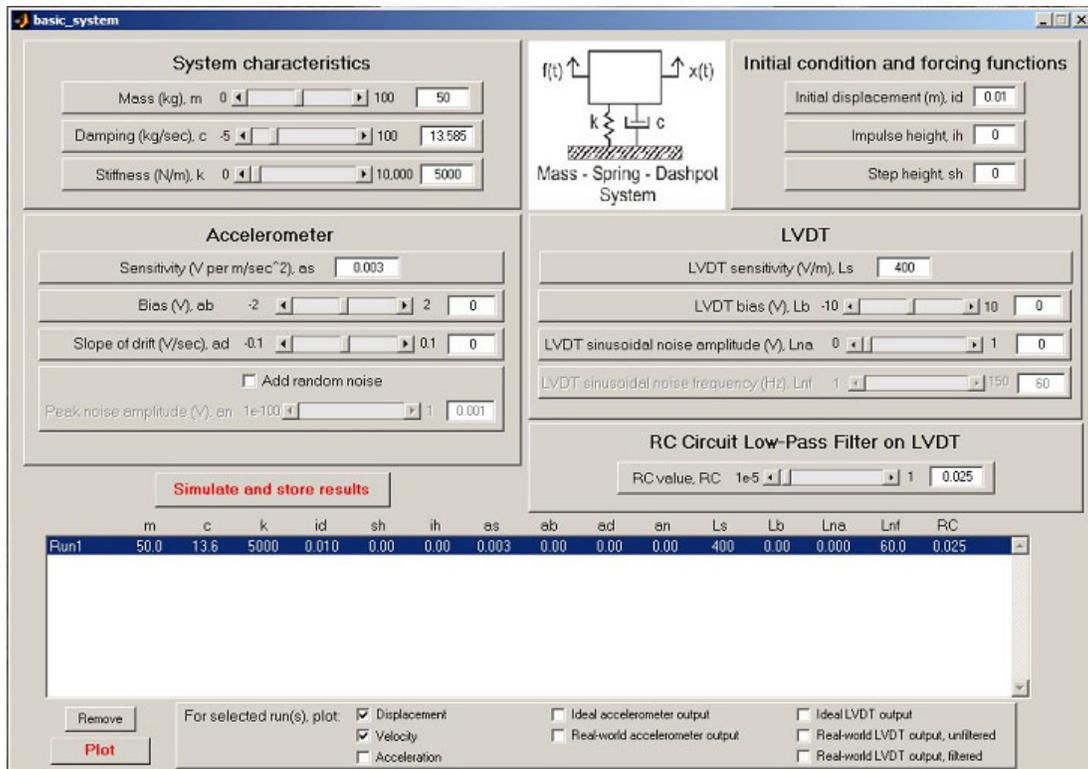


Figure 7 - Virtual Representation of an Actual Measurement System GUI

Numerical Integration and Differentiation GUI

The processing of measured data can be an overpowering experience, especially when measured data is contaminated by real world measurement problems. There are numerous measurement issues that contaminate the actual response of the system that are related to instrumentation and transducer considerations as well as noise. In order to assist the student in deciphering the data, analytical data is used as a baseline and measurement effects typically observed are added to “contaminate” the actual signal. The types of “controlled” contaminations that can be added to the signal are bias, drift, random noise, and sinusoidal noise. The actual signal and “contaminated” signal are displayed in an overlay plot and then the differentiated or integrated signal are displayed in a separate overlay plot. Since the effects added to the measurement are known, the student can easily see how the data is effected by any distortion in the processed data.

The processing is accomplished with the MATLAB GUI shown in Figure 8. The students specify the amount of distortion to contaminate their signals via keyboard entry or scroll bar values.

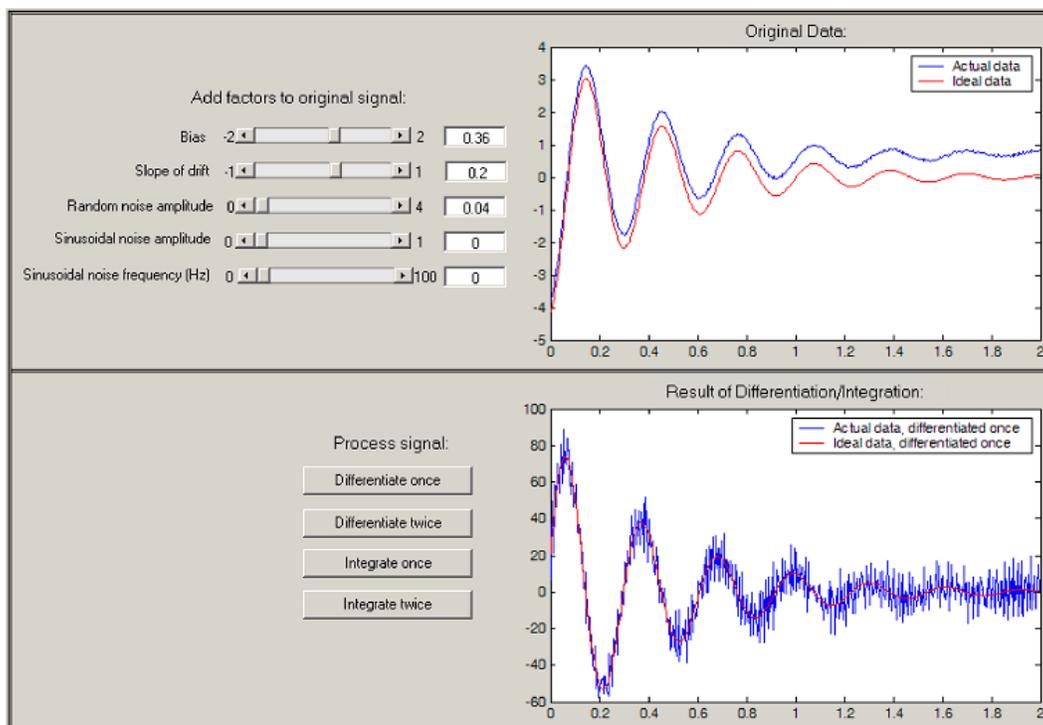


Figure 8 - Virtual Representation of an Actual Measurement System GUI

Conclusion

A new multise­mester interwoven dynamic systems project was described in this paper. The salient feature of the project is that material from various courses such as differential equations, mathematical methods, laboratory measurements and dynamic systems is integrated in a fashion that helps the students understand the need for basic STEM (Science, Technology, Engineering and Mathematics) material. The material is presented with a “theme” project that is re-iterated throughout the multise­mester sequence so that the students understand the inter-relationship of related material from subsequent pertinent courses. The overall material for the first phase is described along with a description of simulation modules developed

Acknowledgement

Some of the work presented herein was partially funded by the NSF Engineering Education Division Grant EEC-0314875 entitled “Multi-Semester Interwoven Project for Teaching Basic Core STEM Material Critical for Solving Dynamic Systems Problems”. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors are grateful for the support obtained from NSF to further engineering education.

References

- 1 Barrows, H.S., “A taxonomy of problem-based learning methods”. Medical Education, 1986. 20: p. 481-486.
- 2 Altmans,C. Turns,J., Mabbering,F. “Integrating Knowledge Across the Curriculum”, 29th ASEE/IEEE Frontiers in Education Conference, 0-7803-5643-8/99 San Juan, Puerto Rico, Nov 1999
- 3 NSF, Restructuring Engineering Education: A Focus on Change, 1995, Division of Undergraduate Education, Directorate for Education and Human Resources, National Science Foundation: Washington, D.C
- 4 NRC, Engineering Education: Designing an Adaptive System. 1995, Washington, D.C.: National Academy Press.
- 5 ASEE, Engineering Education for a Changing World: Project Report, . 1994, ASEE: Washington, D.C
- 6 Starrett,S., Morcos,M., “Hands-On, Minds-On Electric Power Education”, Journal of Engineering Education, Vol 90, No. 1, pp93-100, January 2001

Peter Avitabile is an Associate Professor in the Mechanical Engineering Department and the Director of the Modal Analysis and Controls Laboratory at the University of Massachusetts Lowell. He is a Registered Professional Engineer with a BS, MS and Doctorate in Mechanical Engineering and a member of ASEE, ASME, IES and SEM. **Stephen Pennell** is a Professor in the Mathematics Department at the University of Massachusetts Lowell. **John R. White** is a Professor in the Chemical Engineering Department at the University of Massachusetts Lowell.