IMECE2004-61034

DEVELOPING A MULTISEMESTER INTERWOVEN DYNAMIC SYSTEMS PROJECT TO FOSTER LEARNING AND RETENTION OF STEM MATERIAL

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ABSTRACT

Students generally do not understand how basic STEM (Science, Technology, Engineering and Mathematics) material fits into all of their engineering courses. Basic material is presented in introductory courses but the relationship of the material to subsequent courses is unclear to the student since the practical relevance of the material is not necessarily presented. Students generally hit the "reset button" after each course not realizing the importance of basic STEM material. The capstone experience is supposed to "tie all the pieces together" but this occurs too late in the student's educational career.

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 to be addressed by the new approach. The description of the project and modules under development are discussed.

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. Students are presented material in a sequential format that builds up a set of tools necessary for upper level specialized courses in their particular field of study (mechanical, civil, chemical, etc). 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. This is not only from one course to another but also within a given semester, where students often inquire if material from the first test will be included in subsequent tests. The way courses are usually presented reinforces this incorrect attitude towards the material. Figure 1 captures the essence of the problem encountered by all professors.
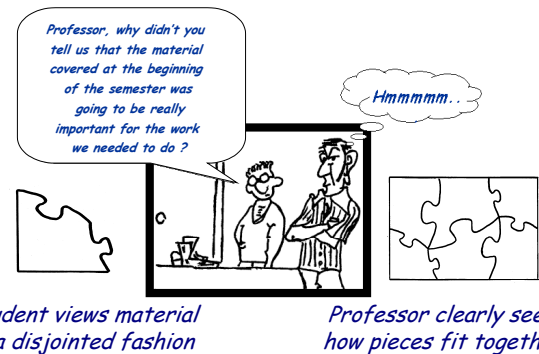

Figure 1 – Professor vs. Student View of Material Presented

The STEM material must 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. The disjointed presentation of the material must cease if this is to happen.

Real engineering problems are rarely solved by "looking up answers at the back of the book". Yet many engineering courses are taught this way and 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. This is too late for them to realize the importance of earlier course material.

BASIC CONCEPTS (OR GOALS AND OBJECTIVES)

Many different approaches (ie, ODE, Laplace, Fourier, Numerical Methods, etc) can be used to solve the same problem but generally these are covered in different courses. What typically happens is that the students don't make the interconnect of the relationship of this material because each technique is applied to a different problem. 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.

For the interwoven project concept, a simple RC circuit and a simple single degree of freedom mass-spring-dashpot system are suggested for the evaluation problems since these problems are generic to all engineering. 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. The material is germane to solving dynamic problems.

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 illustrates the need of employing all the STEM tools. 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. The effort for the entire project can be broken down into the following basic grouping:

Phase 1 Develop analytically oriented material to address the problems and techniques for solving dynamic system problems. The intent is to provide analytical tools but also address the anticipated problems encountered in a real measurement environment

Phase 2 Develop experimentally oriented acquired data that extends the application of previously identified analytical techniques and addresses measurement issues associated with collecting real world data

Phase 3 Implement materials generated in another discipline and another institution. Modify and enhance of all materials based on feedback

Only the material connected with Phase 1 is nearing completion at this time and is discussed in this paper. Phase 2 and 3 have not been initiated as yet. Aspects of Phase 2 and 3 work will be the subject of future papers.

Technical Materials Developed

For the first phase of this project, a series of different tutorial modules have been developed to address first and second order systems. These tutorials 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 tutorials 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 Ccondition Responses with ODE and Block Diagrams
Mathematical Modeling Considerations
Simulink and MATLAB Primer Materials
Miscellaneous Materials

Many of the tutorials are supplemented with MATLAB and Simulink scripts – 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.

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 but using the frequency domain rather than
the time domain response approach. Concepts of time
response, cutoff frequency, 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, 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 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, order model, etc. to view the effect on the
computed analytical model that best describes the data.

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

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 of 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 differentiate 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
"contaminated" signal to see the effects of distortion when
processing data.

S-Plane 3D – a MATLAB GUI allows the user to explore the S-Plane through a GUI interface to see the effects of parameters on the system characteristics

Frequency Response Function – 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.

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.

Single DOF Complex 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 is 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.

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.

First Order Low Pass Filter

The definition of a 1st order system is fairly straight-forward. However, the frequency filter characteristics are not so obvious from 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. The MATLAB GUI is 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. 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.
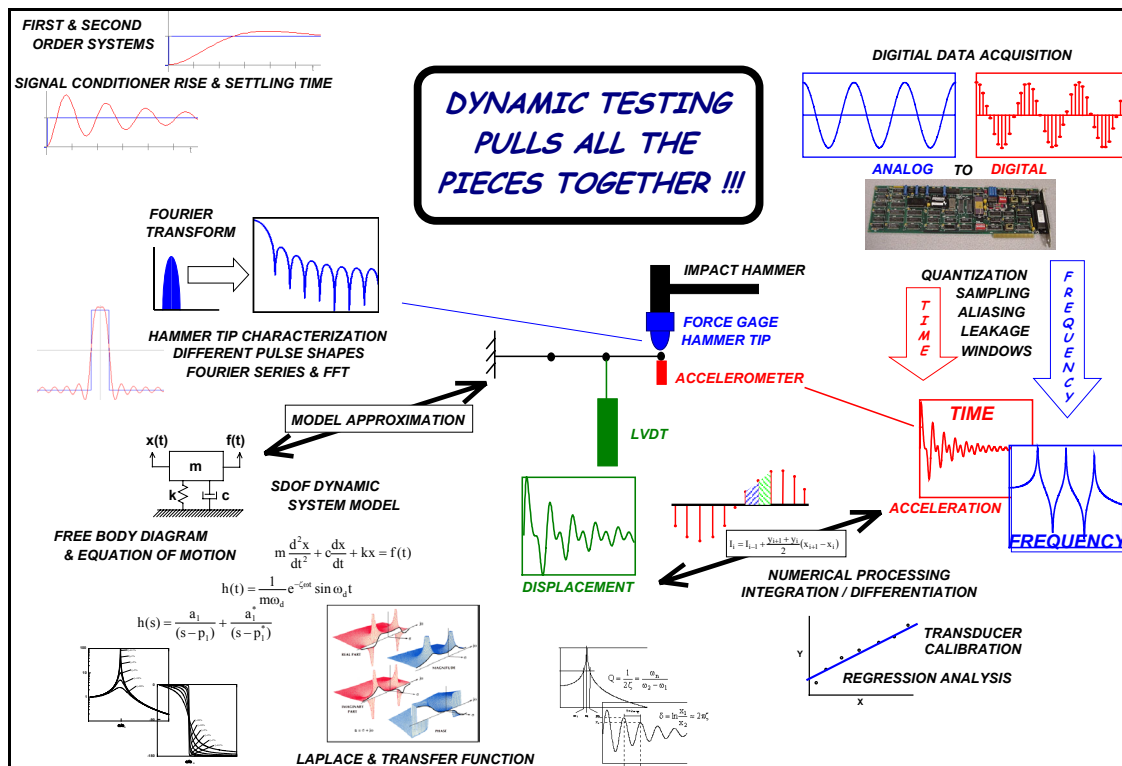
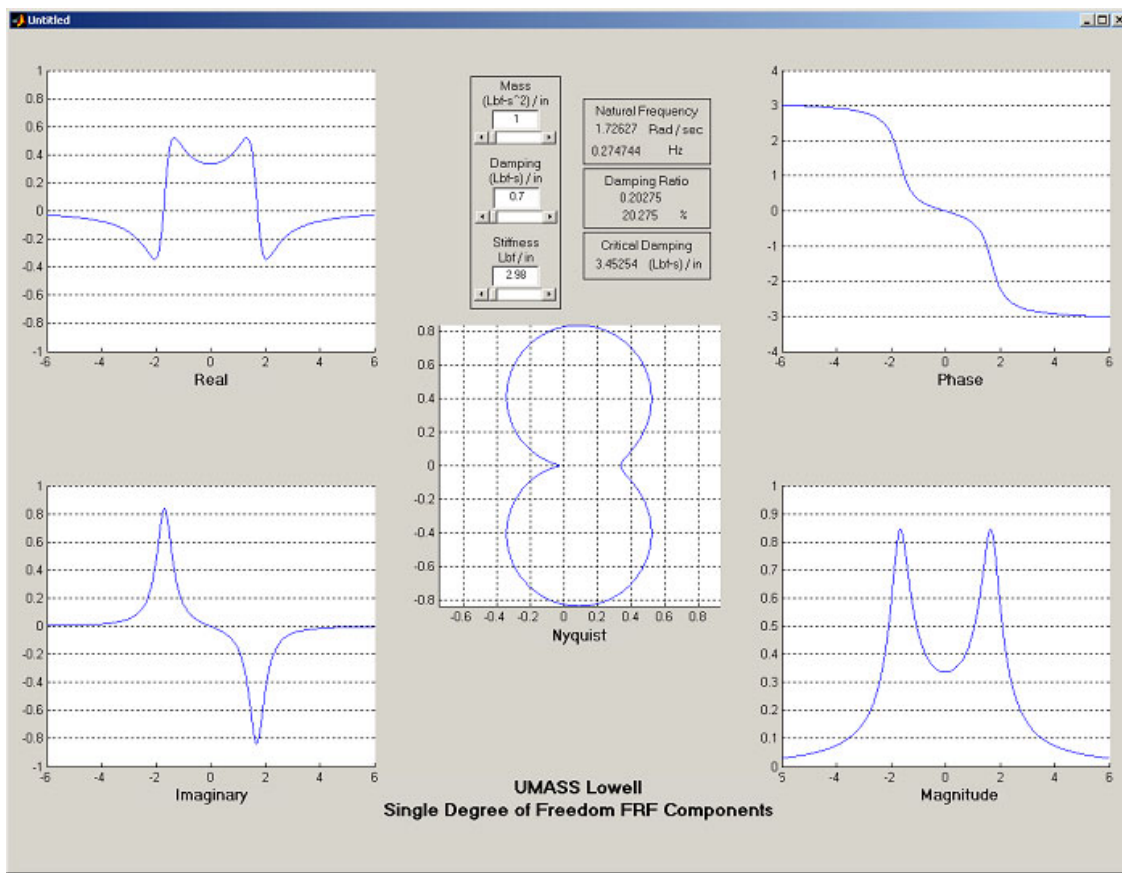Figure 2 – Concept Schematic of Interwoven Material

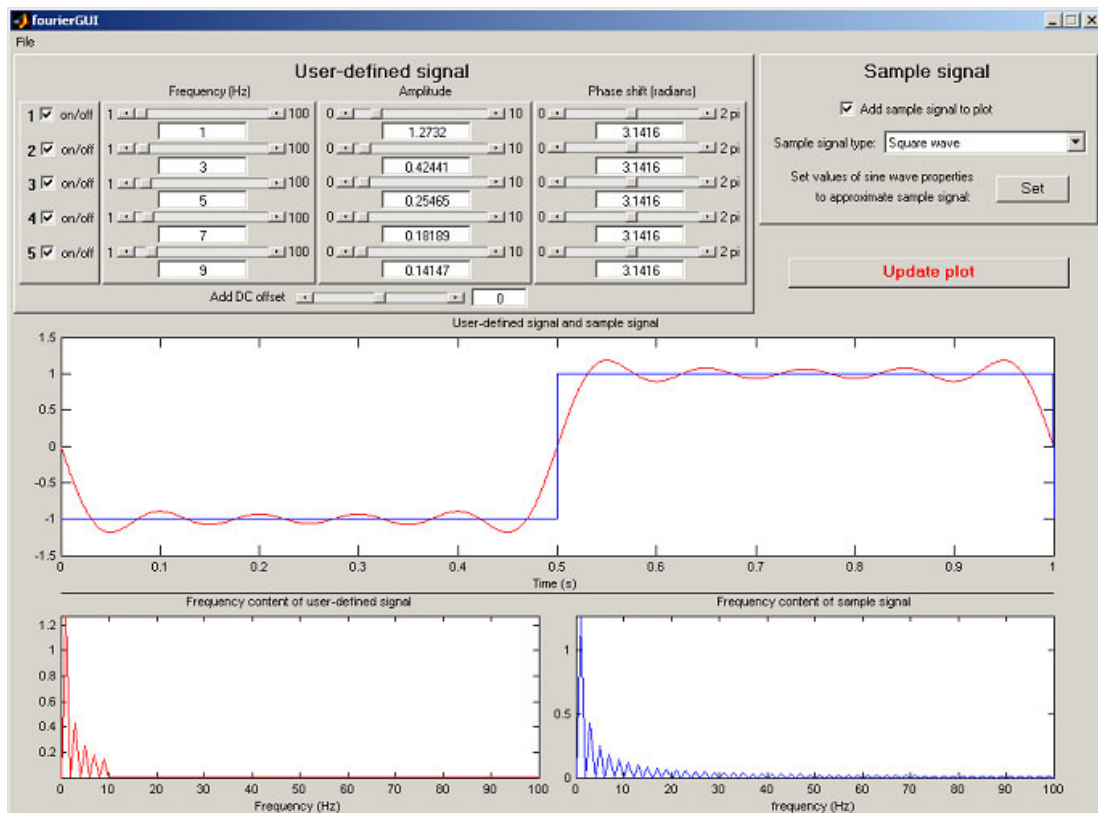Figure 3 - Single DOF Complex FRF Plot GUI

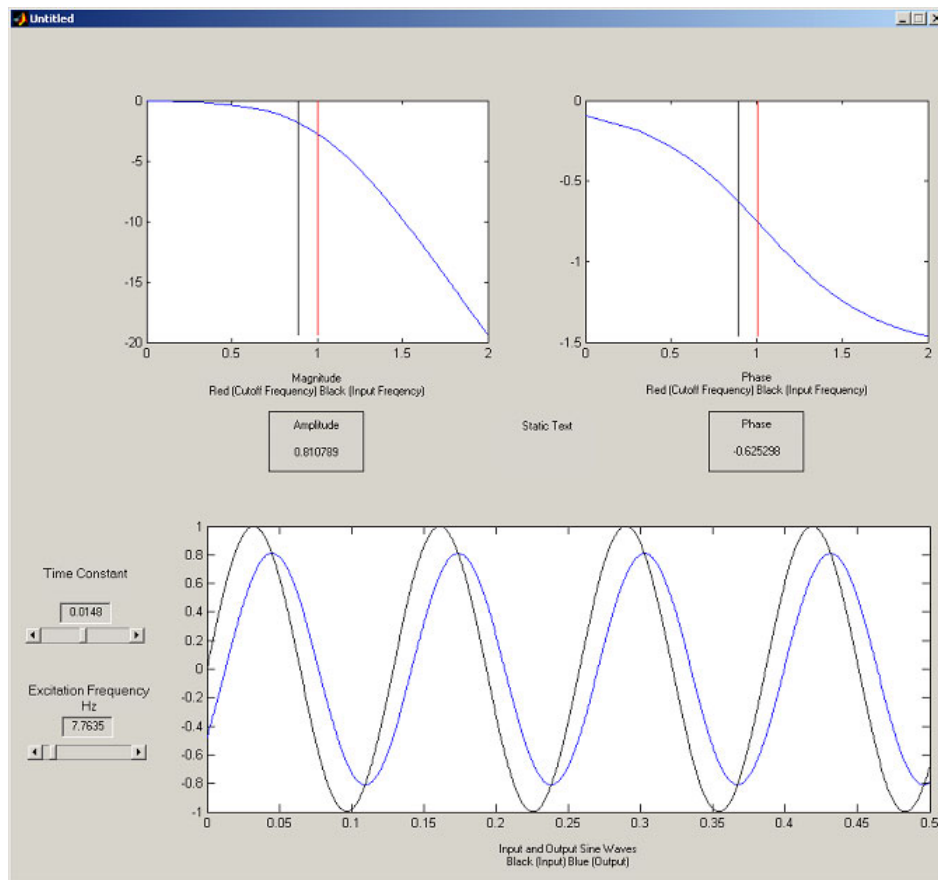Figure 4 - Fourier Series Signal Generation GUI
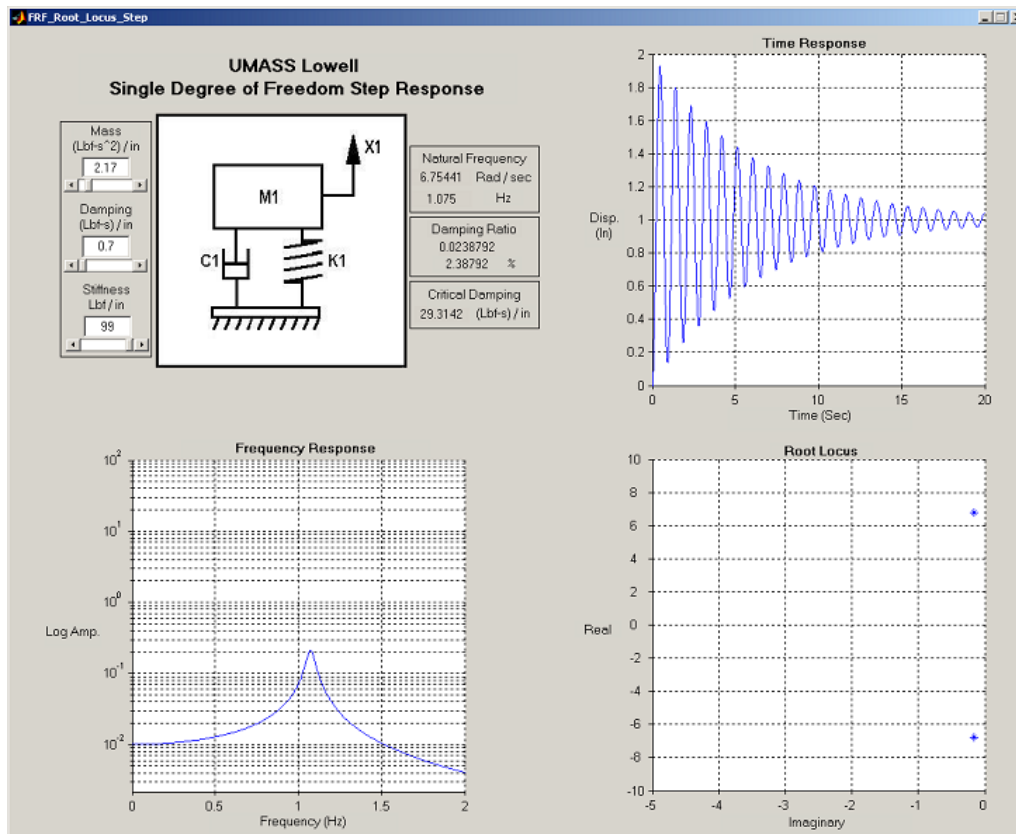

Figure 5 - First Order Low Pass Filter GUI

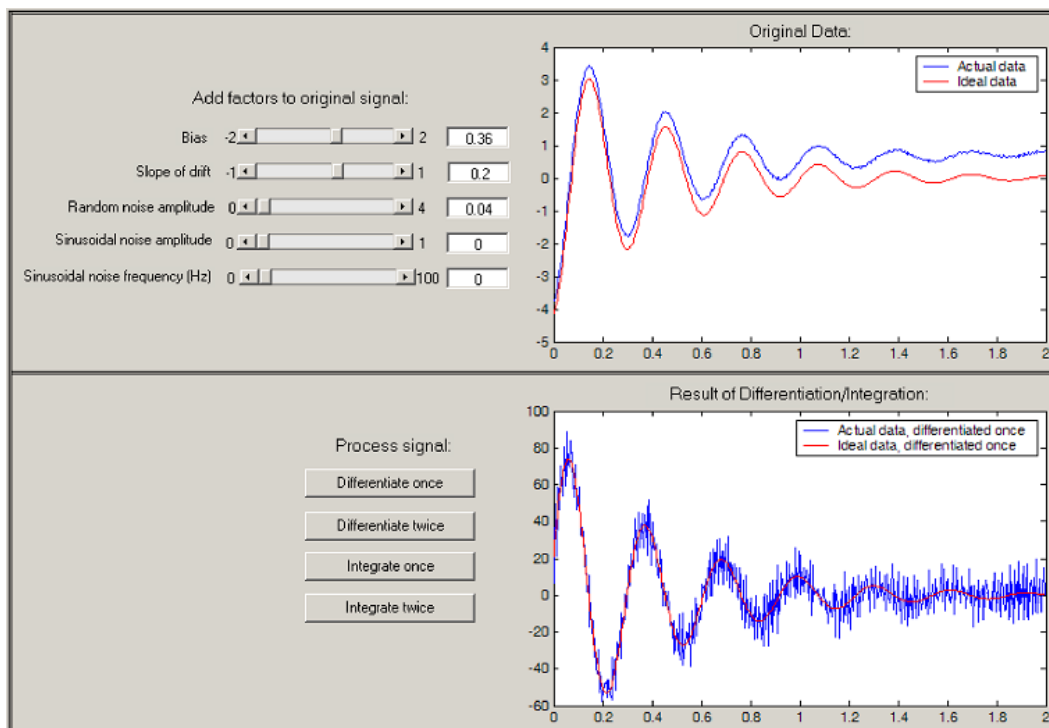Figure 6 - Second Order System Step Response GUI

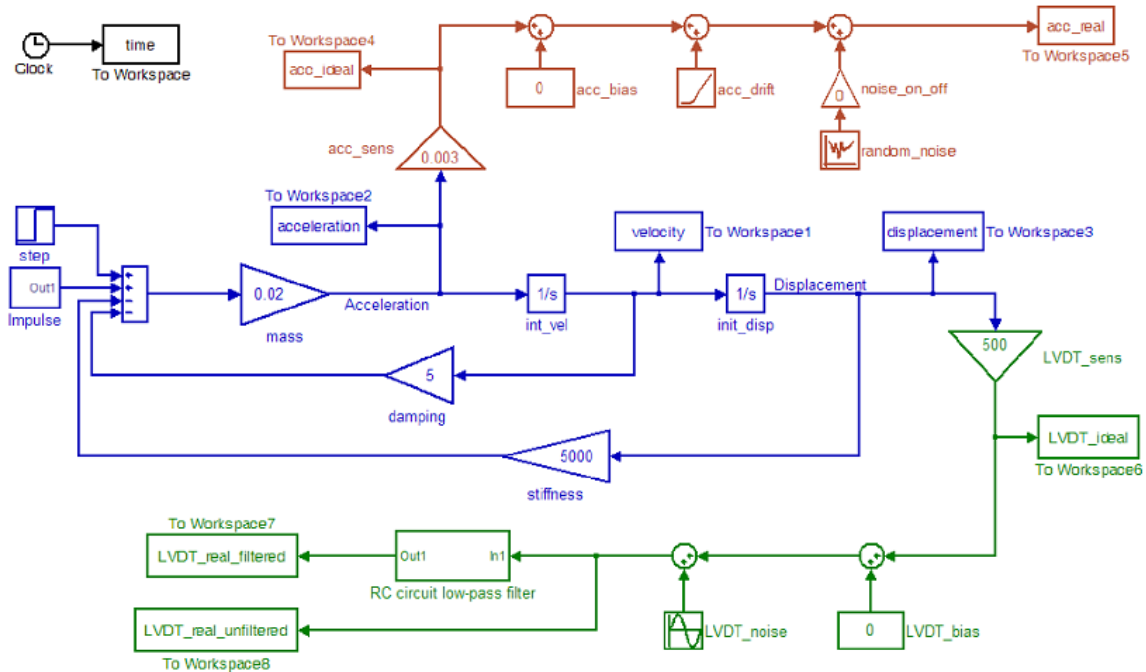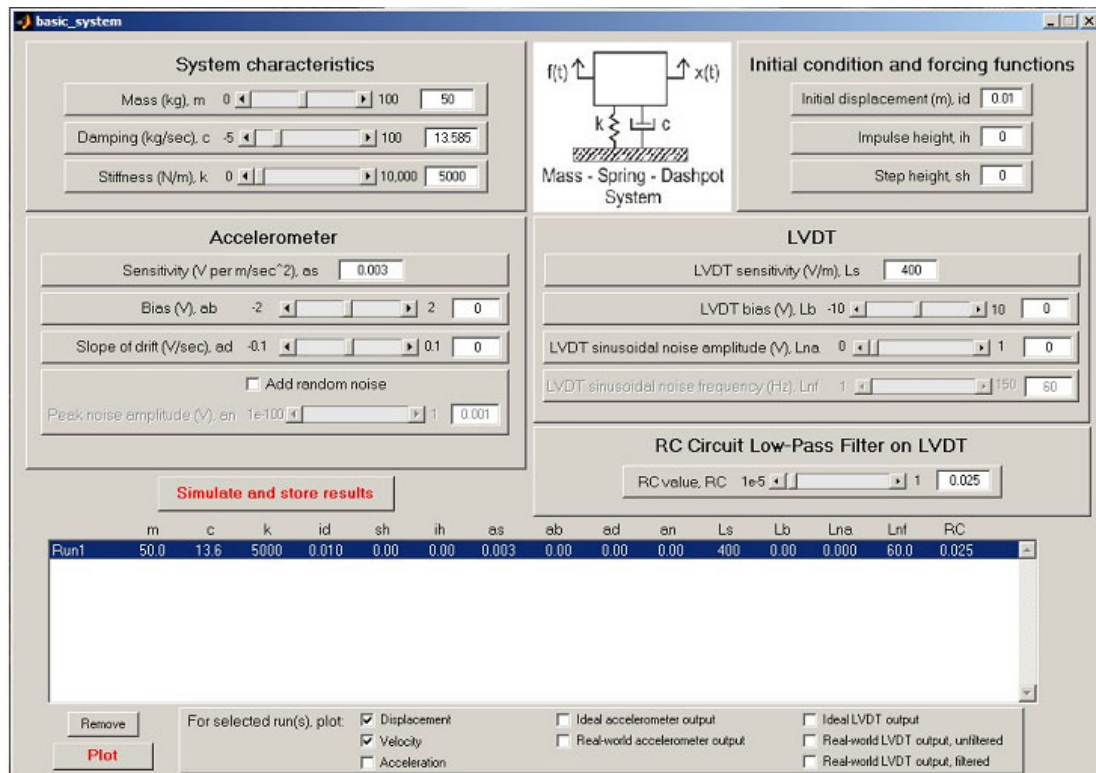Figure 8 - Virtual Representation of an Actual Measurement System GUI

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.

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.