AC 2007-2053: AN INTEGRATED UNDERGRADUATE DYNAMIC SYSTEMS TEACHING METHODOLOGY UTILIZING ANALYTICAL AND EXPERIMENTAL APPROACHES

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ABSTRACT

The problem in teaching undergraduates basic dynamic systems analysis is that all of the course material that leads up to this upper level course is typically taught in a disjointed fashion. A new variation of this course along with the prerequisite courses has been adopted in the UMASS Lowell Mechanical Engineering program. An interwoven, multi-semester approach has been used and has progressively evolved over the past several years. The new approach integrates materials that are taught in Differential Equations, Mathematical Methods for Engineers, Mechanical Laboratory courses and then onto the Dynamic Systems course. Some novel approaches for presenting the material along with hands-on experimentally acquired data have been developed. The Response Under Basic Excitation (RUBE) online experiment along with all of the supporting analytical and virtual tools that have been developed over the past several years under an NSF funded project are described in this paper. All materials are available online at http://dynsys.uml.edu/.

1 - PROBLEM

Generally, students do not understand the need for basic STEM (Science, Technology, Engineering and Mathematics) material that is critical to the solution of engineering problems. Unfortunately, closely related material may be spread out over several courses. By the nature of the structure of semesters (or quarters), material is grouped together into logical units to allow for material to be deployed in a controlled fashion with a specific timetable that integrates the material in the student's academic career. Unfortunately, students don't understand this. As far as they are concerned, the material does not appear to have any connection to other material from previous courses. This then makes the material appear to be unimportant. Students naturally tend to hit the "reset button" after each and every course since there is no apparent reason to want to actively retain the information. All professors encounter this problem as depicted in Figure 1.

In order for STEM material to become an integral part of the student's knowledge base throughout their entire educational and professional careers, the students must, in essence, "live the material" every day and in every course [1-5]. To foster this approach, material must be presented in a more cohesive fashion. The efforts described in this paper are an attempt to overcome some of these issues through the use of a better integrated deployment of the material with a general theme that exists throughout all the courses where the material is developed and delivered.

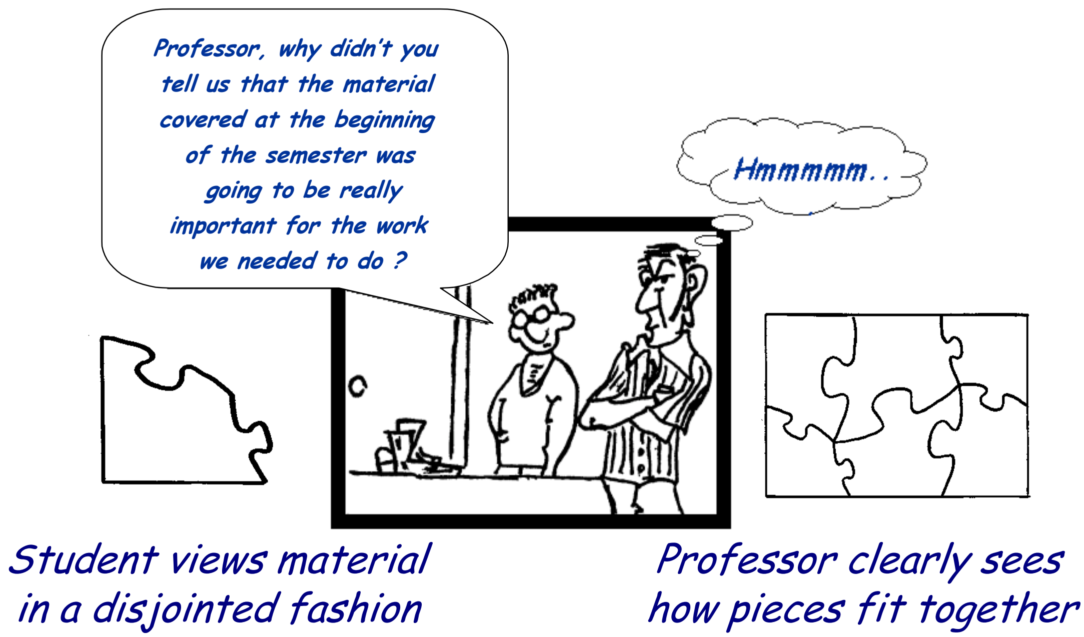


Figure 1 – Professor vs. Student View of Material Presented

2 - INTRODUCTION

The mission for all instructors is to educate their students in the most efficient manner possible. Teaching techniques should challenge, educate and promote innovative thinking from students. The lecture-based format of teaching which predominates in engineering education may not be the most effective manner to achieve these goals [1,2]. Constructivist learning theory asserts that knowledge is not simply transmitted from teacher to student, but is actively constructed by the mind of the learner through experiences. [3,4].

Students learn best with hands-on projects with practical purpose [5]. Laboratory based projects are the best vehicle for demonstrating many aspects of engineering problem solving situations. However, in most cases, laboratory environments are set up as "exercises" which have very clear, predetermined outcomes. This is done to reinforce lecture material that is presented in related courses [6]. These "canned" laboratory experiments are a strong complement to the course theoretical content. These types of labs have a very well-defined, deterministic outcome which reinforces basic inherent skills that the students need to master. Many professors are comfortable with this approach since the outcomes of the lab experiment are well defined and can be assessed and evaluated with very clear guidelines.

However, this does not exploit the laboratory experience to its fullest. Students get the impression that the experimental environment is very similar to the classroom environment where homework problems and tests have explicit answers, given the problem statement. Unfortunately most, if not all, engineering problems do not follow this cookbook approach. Students must be allowed to experience problems that require them to formulate solutions to problems with no specific straight-line structure to the solution – they must learn how to "think outside the box" [7].

Laboratory (and the senior capstone project) is the one place where students have the opportunity to "think on their own" and assemble separate pockets of knowledge to solve a complete problem. The biggest advantage is that real-world exercises and experimental approaches clearly show that there is not always an "answer at the back of the book". Students are often frustrated by this. But they learn that they need to employ many of their STEM skills in order to solve even the simple problems.

Students must feel comfortable with formulating solutions to problems where no specific solution may be possible or a variety of different solutions may exist. Experiments are a critical part of helping students cope with this unknown situation. Students must also feel comfortable formulating solutions to real engineering problems using all of the STEM tools available to them – not just specific tools developed in a particular course. The STEM must become an integral part of their learning process throughout their entire educational and professional careers – the students must, in essence, "live the material" every day and in every course. Course materials must cease to be presented in a disjointed fashion if this is to happen.

"After two weeks, people generally remember 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they hear and see, 70% of what they say, and 90% of what they say and do."[8] Clearly, the students need to drive the need for learning STEM related material. Once they have been able to clearly identify the need to learn and understand these basic STEM principles, their ability to utilize the concepts and principles in solving real-world engineering problems will be enhanced. Students need to take ownership of the STEM material that is critical to solving engineering problems early in their educational career. Advisors from industry have identified that students need to be exposed to a real-world laboratory environment [9, 10, 11].

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.

3 - 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 because material is taught by many different professors or it is expected that students should see the relationship. What typically happens is that the students don't see the connections between these methods because each technique is applied to a different problem [12]. In order to help the students understand the application of each technique, the same generic problem needs to be incorporated into each course. By showing the application of each technique to the same problem, the resulting similarities and differences can be seen. The basic underlying concept of this effort is to present material in a more cohesive fashion with integration of materials and concepts interwoven between related courses. This fosters student comprehension so they can better grasp the inter-relationship of the basic STEM material. In order to accomplish this, simple first and second order systems are used. These are generic to all engineering problems. From these two simple systems, an array of inter-related concepts can be deployed. 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.

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.

Generally, a well-behaved analytical model can provide very useful "virtual" data for the students to understand and comprehend data. This "well-behaved" data is extremely useful since the model used to develop the data can be perturbed and modified to simulate a variety of different effects that can typically be observed in real data. Note that real data can always be obtained but generally has many contaminants that are simultaneously applied and therefore the student may not be able to interpret the data easily with many effects superimposed. 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 [13].

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 which is critical to solving dynamic systems problems. A strong laboratory component with multimedia and hands-on application of STEM material reinforces theoretical concepts.

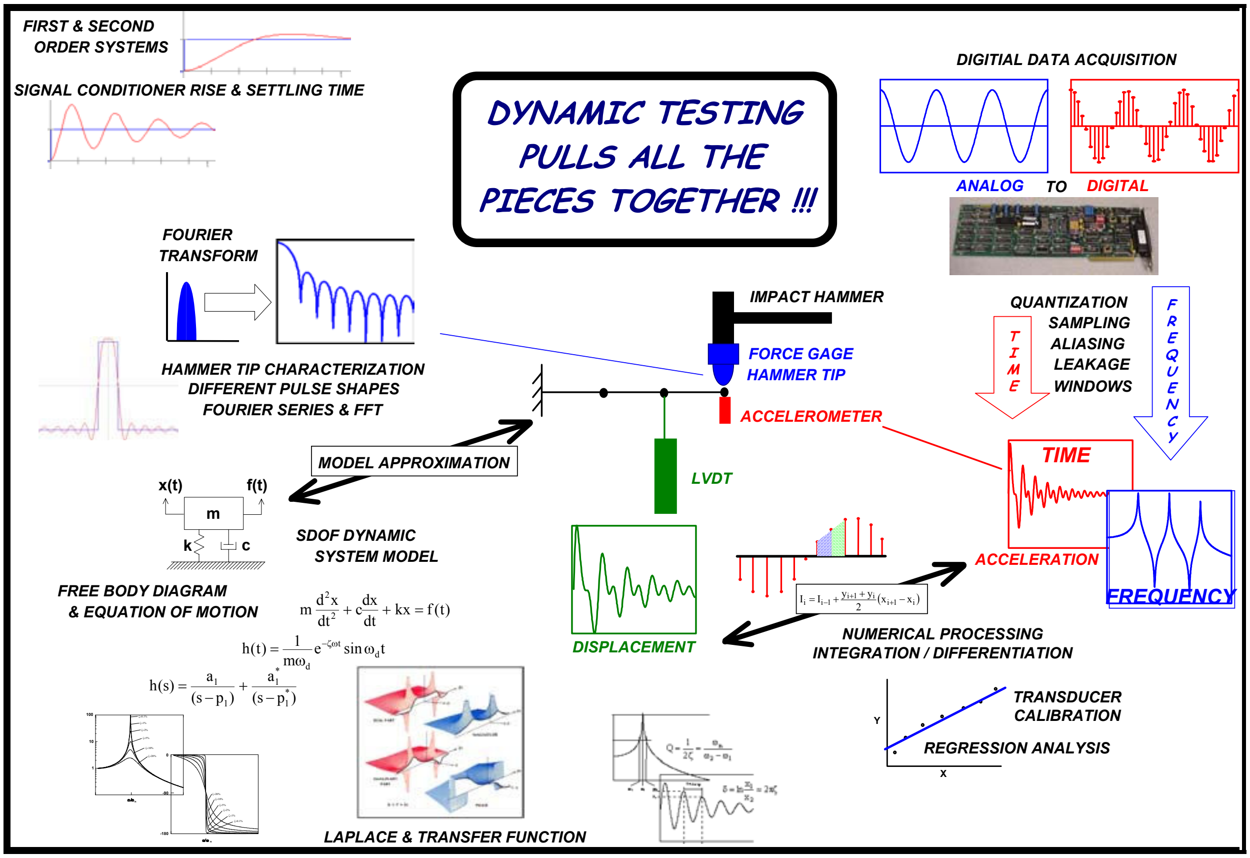


Figure 2 – Concept Schematic of Interwoven Material

4 - BASIC CORE MATERIAL IN THE MULTISEMESTER PROJECT CONCEPT

A series of projects, labs and exercises have been developed that span across several courses to better integrate the material pertinent for solving dynamic systems related problems. While there are many additional items that contribute to this effort, the main pieces are described briefly here to set the conceptual approach and are discussed in more detail later in this paper.

Analytical Tools Developed
A variety of different analytical tools have been developed that span across the entire range of related projects. These include tutorial materials, graphical user interfaces (GUI) and voice annotated material and exercises related to these important tools. (see Section 5)

Experimental Online Measurement System
An online measurement system has been developed to address the response of a second order mechanical system. The RUBE (Response Under Basic Excitation) allows the students to acquire a set of data for a mechanical system that has variable parameters. There are many different applications where this measurement system can be used. (see Section 6)

Project: Numerical Integration and Differentiation for a Second Order System
A simple second order mechanical system is used to measure displacement and acceleration response. However, the measurements are not very good and suffer from a variety of contaminants. This very clearly emphasizes some of the issues that must be addressed when differentiating or integrating data with noise, drift, bias and other contaminants. This project is important in extending the students knowledge of numerical processing of real data which is not as well behaved as the analytical data presented in other courses. (see Section 7)

Project: Development of a LabVIEW Interface for Fourier Series Approximations
A LabVIEW interface is developed to illustrate Fourier Series concepts along with filtering. This is important for later material related to response of arbitrary inputs but also important for the understanding of filtering for noisy signals. This project is also important to later lab projects where spectral measurements are made that have noise, harmonics, and spectral considerations when balancing rotating equipment. (see Section 8)

Project: Dynamic Systems Laboratory Based Hands On Project
Analytical approaches for addressing dynamic systems are strongly reinforced with an experimental measurement system to identify system characteristics. The measurement system has variable properties which makes each data set unique from other data sets. A later project allows the students to merge concepts from earlier projects to properly design a filter and process the data. A final project requires the students to develop a Simulink model to compute response of a second order system with the use of Fourier Series concepts. . (see Section 9)

Project: Design of a Measurement System for a Second Order Mechanical System
A mini-capstone "design of measurement system" for a second order dynamic system requires the students to identify measurement system requirements through the use of all earlier material developed. The students have complete control of selection of measuring equipment,

analytical approaches utilized and processing performed. (see Section 10)

While there is much more material that has been integrated into the curriculum in homework and assignments, only the significant, basic core material is described in this paper. Several of the projects are described in the following sections along with some of the ancillary material that supports all of this effort.

5 - ANALYTICAL TOOLS

A wide variety of different analytical tools have been developed along with tutorial material to address the majority of issues related to this integration of dynamic systems material. All materials developed are available on the project website (http://dynsys.uml.edu) which is shown in Figure 3 along with an image map identifying all the materials developed. A series of inter-related tutorials covering a variety of pertinent materials were 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 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

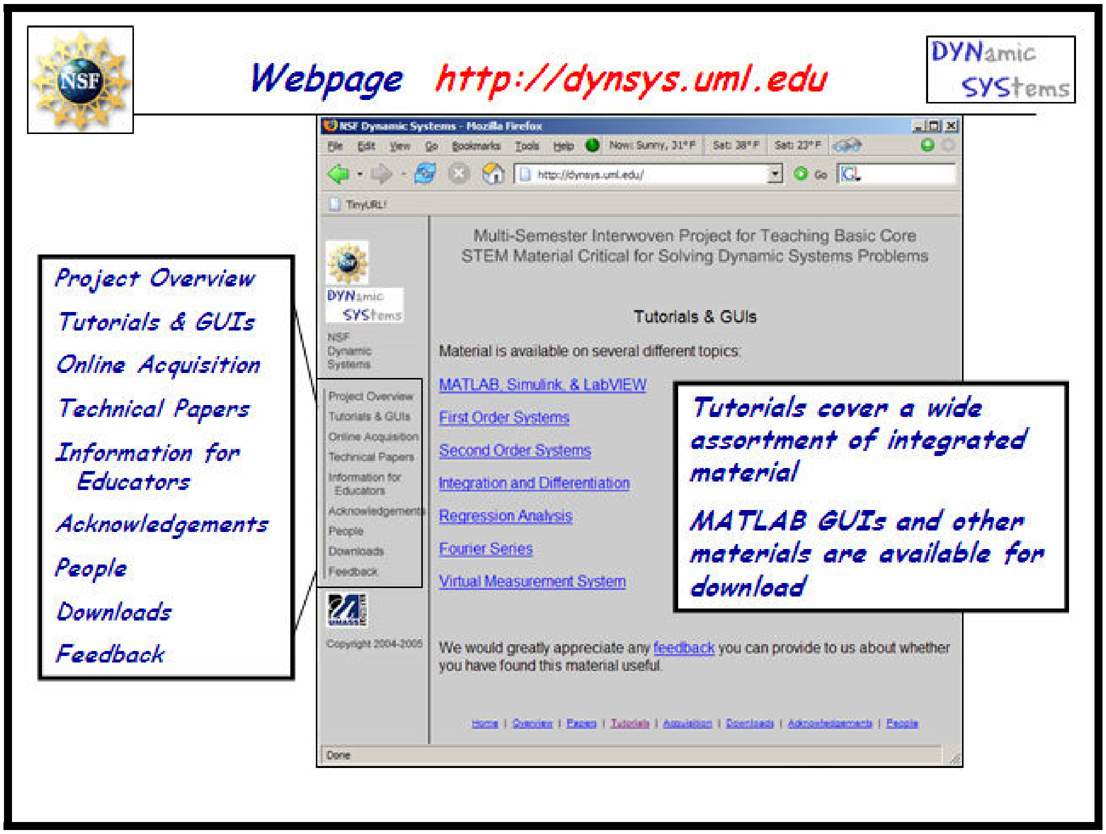
Second Order Systems
- Modeling Step, Impulse, and Initial Condition with ODE and Block Diagrams

Mathematical Modeling Considerations
- Fourier Series, Integration/Differentiation, Regression Analysis

Miscellaneous Materials
- Simulink and MATLAB Primer Materials
- LabVIEW Tutorial 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 MATLAB and LabVIEW have been used to generate Graphical User Interfaces (GUI). A GUI allows for the easy adjustment of parameters so that the student can explore various system parameters and the effects on system response. A brief description of each of the tutorials and GUIs is presented in Appendix A along with examples. (All GUIs and exercises are also available on the web as voice annotated presentations to explain the material.)

It is important to note that these tutorials and GUI materials are delivered at various times in the multi-semester project – sometimes before a project is given to get the students ready but sometimes after a project has been completed to help the students better understand some of the issues that needed to be addressed during a given exercise or project.



CLICK HERE FOR ERRATA		1st Order: RC Step	1st Order: RC Filtering	1st Order: Tank Problem	2nd Order: Initial Conditions	2nd Order: S-Plane	2nd Order: Step	2nd Order: Impulse	2nd Order: System Response	2nd Order: Complex FRF	2nd Order: Convolution Arb.	2nd Order: Convolution SDOF	2nd Order: Motor MDOF	Miscellaneous: Fourier	Miscellaneous: Regression	Miscellaneous: Int/Diff	Miscellaneous: Windowing and Leakage	Miscellaneous: VMS
General Theory	PDF		P						P									
Tutorial	PDF	P	P		P		P	P			P		P	P	P	P		
Block Diagram			P						P									
Matlab GUI	Tutorial	P	P	P	P	P	P	P		P				P	P	P		P
Matlab GUI	Download	6 7	6 7	6 7	6 7	6 7	6 7	6 7		6 7				6 7	6 7	6 7		6 7
Matlab GUI	Download	MR	MR	MR	MR	MR	MR	MR		MR					MR	MR		
Matlab GUI	Voice	F	F		F	F	F	F		F				F	F	F		F
Matlab GUI	Voice	A	A		A	A	A	A		A				A	A	A		A
Excercise	PDF	P	P	P	P	P	P	P		P				P	P	P		P
Excercise	Voice	F	F		F	F	F	F		F				F	F	F		F
Excercise	Voice	A	A		A	A	A	A		A				A	A	A		A
LabVIEW GUI	Download	VR	VR		VR		VR	VR	VR		VR	VR	VR	VR			VR	
LabVIEW GUI	Tutorial	P	P		P		P	P	P		P		P	P			P	
LabVIEW GUI	Voice	F	F		F		F	F	F					F			F	
LabVIEW GUI	Voice	A	A		A		A	A	A					A			A	
Excercise	PDF	P	P		P		P	P	P					P			P	
Excercise	Voice	F	F		F		F	F	F					F			F	
Excercise	Voice	A	A		A		A	A	A					A			A	

	Intro			GUI Instruction														
LabVIEW	P	F		P	F	Add Signals	F	FFT of Signal	F	Filter Signal	F	Change Controls	F	Change Indicators	F	Merge Block	F	While Loop
Matlab		F	A	P	P	Import/export to Excel	P	Command List										
Simulink	P	F	A		P	LTI Viewer and MUX Block	P	Block List	P	Modeling an Impulse	P	State Space and Transfer Function						

	RUBE 1	RUBE 2
Overview	P	P
Pre-Recorded Data	R	R
Assignment	F	F
Online Acquisition	R	R

LEGEND			
P	PDF File (Requires Acrobat Reader)	VI	LabVIEW VI File (Requires LabVIEW 7.1)
6	MATLAB p File (Requires MATLAB 6.5)	VR	LabVIEW EXE File (Includes Runtime Engine)
7	MATLAB p File (Requires MATLAB 7.0)	F	Voice Annotated Flash (Requires Flash Plugin)
MR	MATLAB EXE (With Runtime Engine)	A	Voice Annotated AVI (NOT Streamed - Large
R	RUBE related material		

Figure 3 – Project Website – *http:dynsys.uml.edu* and Image Map for all Materials Developed

6 - EXPERIMENTAL ONLINE MEASUREMENT SYSTEM DEVELOPED

To complement the analytical tools developed and to provide access to data for further exploration of first and second order systems, an online data acquisition system was developed. The system consists of a simple mass-spring-dashpot system that is instrumented to measure its response due to initial conditions or an impulsive force.

The online data acquisition system has been designed to have several unique features in terms of its overall performance. The system is designed to have both variable mass and variable stiffness characteristics which change every time the system is started by a remote user. This guarantees that the system is not known and can be used time and time again by the same student. The student can then utilize all of their knowledge and skills to determine the system characteristics and deal with the issues related to data which is not always perfect and is contaminated by a variety of features inherent in transducers, their signal conditioners and noise. A diagram of the basic system, RUBE (Response Under Basic Excitation), is shown in Figure 4. The system is available as an online experiment. Students have access to the experiment over the internet using a LabVIEW Web-based Interface. A photo and sketch of the system and a screen capture of the LabVIEW Interface are shown in Figure 5.

Several important features need to be mentioned regarding the RUBE system. Every time the system is accessed, the system parameters are changed. First, the mass of the system is constantly changing due to a slowly varying water level controlled by a float/pump system. In addition, the stiffness of the leaf spring support system changes each time the system is run – the spacing of the support location changes. In this way, every student receives a set of data which is slightly different than any other set of data collected by other students. The excitation of the system is obtained by a variable impact force or one of three different input displacements from a motor driven cam system. The RUBE system is designed to have mass, damping, stiffness and natural frequency that typically has 15 to 20% variation in values due to the changing parameters of the system. In this way, students have a different set of characteristics every time the system is run. The RUBE system is described in more detail in [12,13]; the reader is directed to those references for detailed information on the system characteristics.

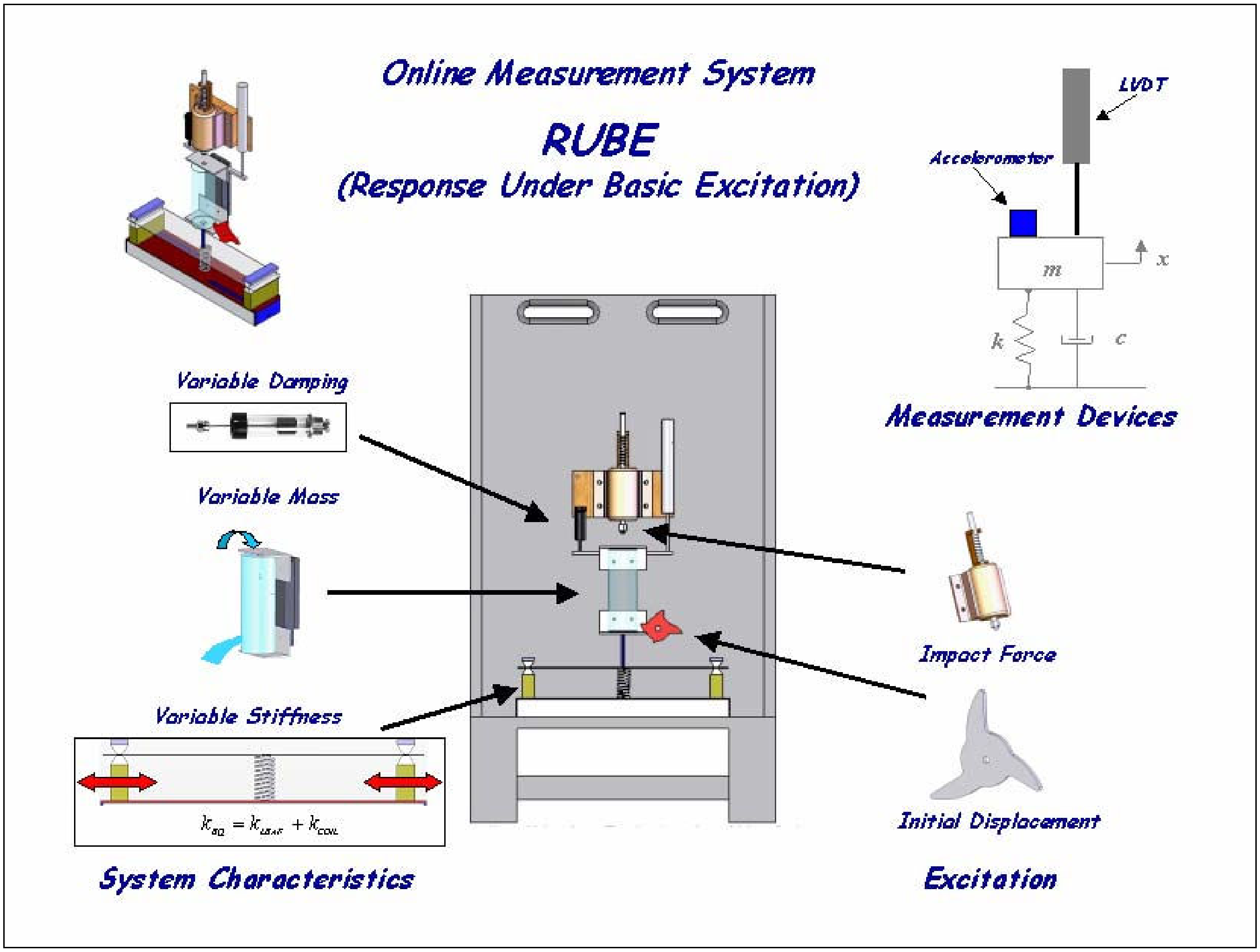


Figure 4 – Schematic of the Various Components of the Online Measurement System

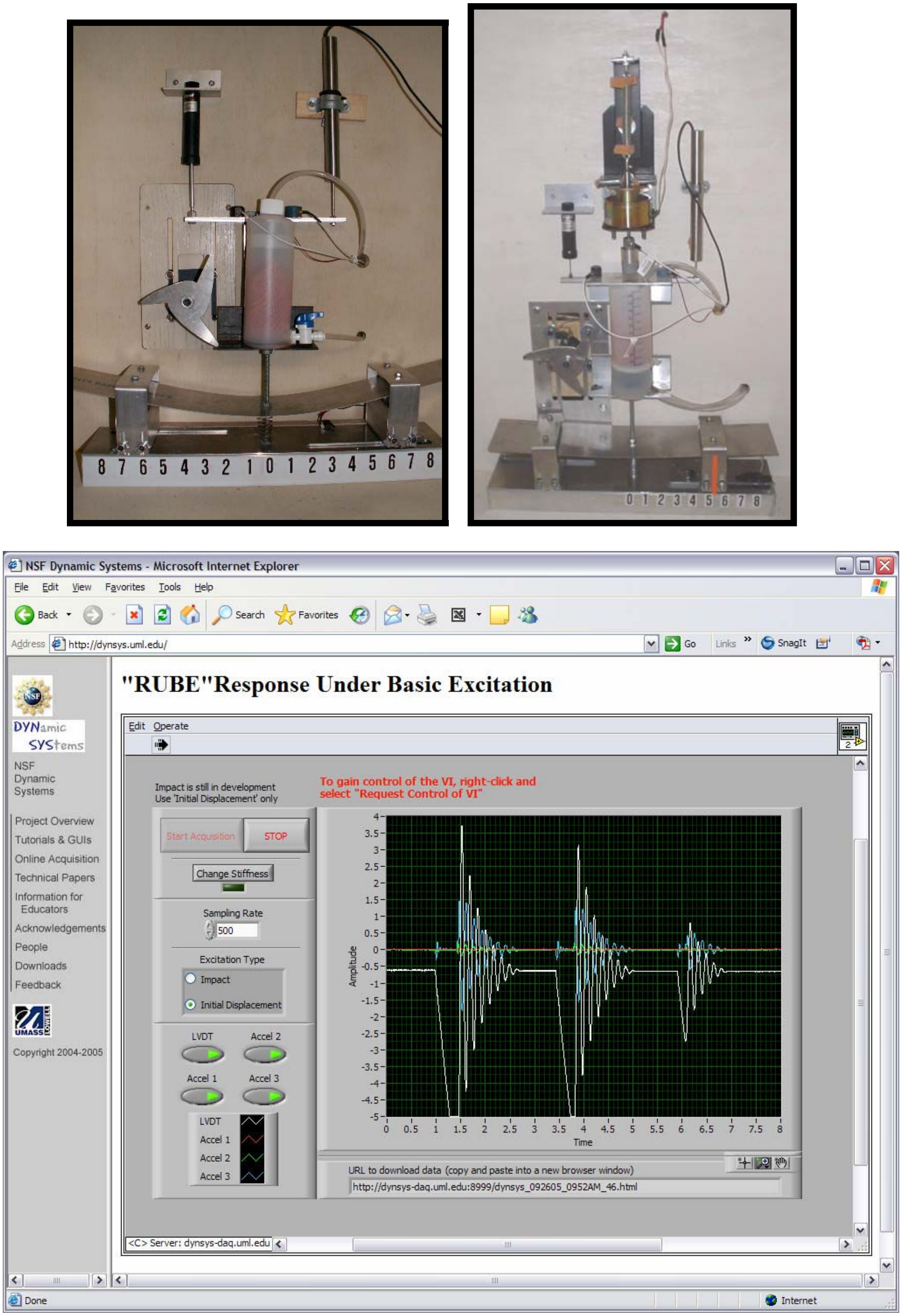


Figure 5 – Photo (RUBE I and RUBE II) of MCK System along with LabVIEW Interface

7 – PROJECT: NUMERICAL INTEGRATION AND DIFFERENTIATION

A set of data is collected for a simple mass, spring, dashpot system with an LVDT and accelerometer. The basic problem is that the measured data is contaminated with noise, bias, drift, offset, quantization error, to name a few issues. This is the first set of data that the students acquire that are NOT the pristine analytical data used in earlier numerical processing courses. Of course the students become confused, frustrated, and bewildered that the numerical processing that has been provided in earlier courses can not be applied directly on the data. This then becomes one of the first times that the students must handle messy data where there is no answer at the back of the book. Eventually, after some struggling, the students start to realize that they must condition the data before blindly applying numerical processing techniques. (Later in the same lab course, the lab is revisited with slightly improved, but not completely corrected, measurements for a final course project.) The students learn from this exercise that the need for good measurements cannot be overemphasized. The need for good signal conditioning, filtering, appropriate sensitivities are realized from this project. Subsequent projects build on this problem from various standpoints. The basic measurement system and setup is shown in Figure 6 along with a some typical measurements that result during this project. This is discussed in more detail in [14,15].

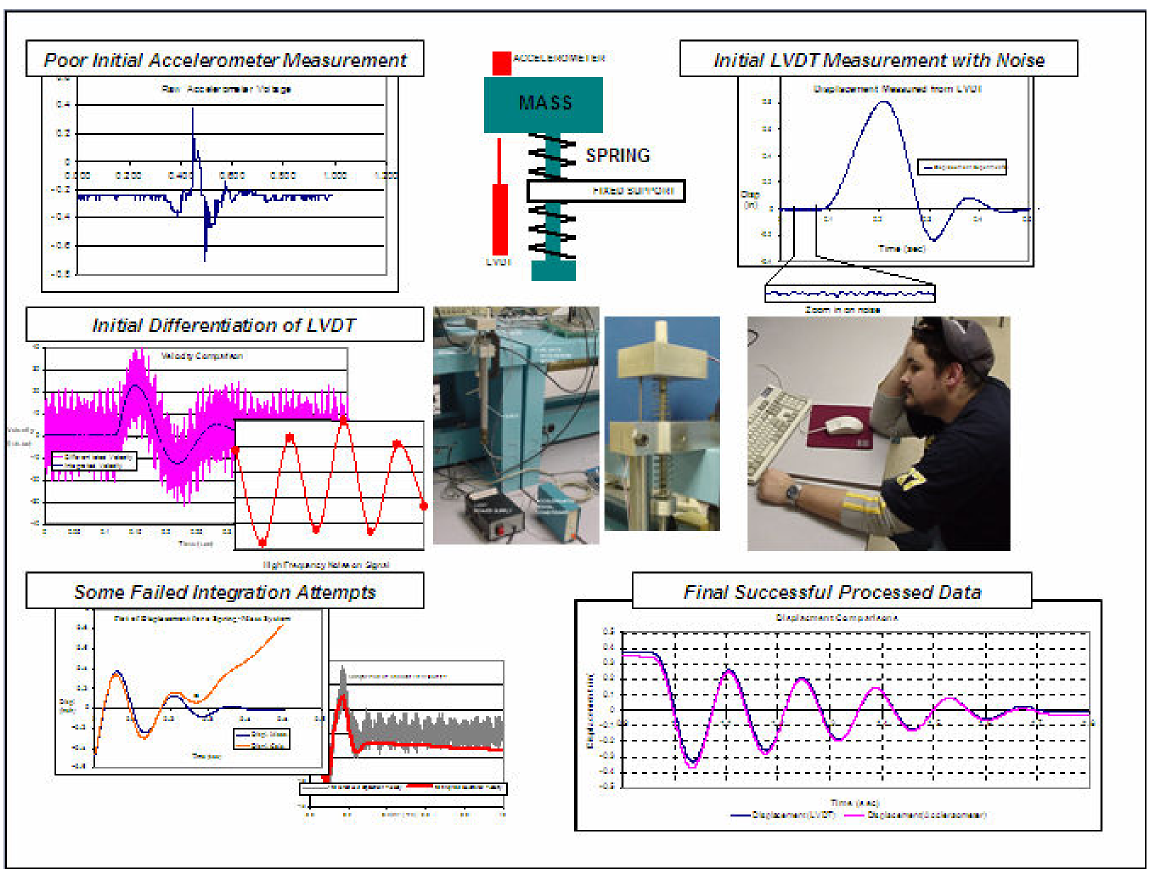


Figure 6 – Overview of Various Aspects of Numerical Difficulties Project

8 – PROJECT: FOURIER SERIES CONCEPTS USING LABVIEW

A project to illustrate Fourier Series concepts along with filtering using LabVIEW provides the students with hands on application of these important tools. The basic intent of the project is to expose the students to these basic tools in an application setting. The students are required to generate a series of sine waves to represent an arbitrary signal such as a square wave, sawtooth or other signals. They see first hand the development of Fourier Series to represent general signals. This project helps them to understand time and frequency representation of signals, harmonics and filters. (In subsequent mechanical engineering labs, the students are better prepared to address characterization of filters and mechanical system response. There are three labs that relate to spectral processing, filter characterization, mechanical response, harmonic information and general time/frequency processing of real data collected in the lab. In later projects, these tools are useful for both analytical and experimental conditioning of measured data.) An overview of some of the pertinent material from the Fourier Series project is shown in Figure 7 along with a some typical measurements that result during this project. This material is discussed in more detail in [16]. There is extensive material on the webpage (PDF and voice annotated notes) that the students used to develop the LabVIEW GUI [17].

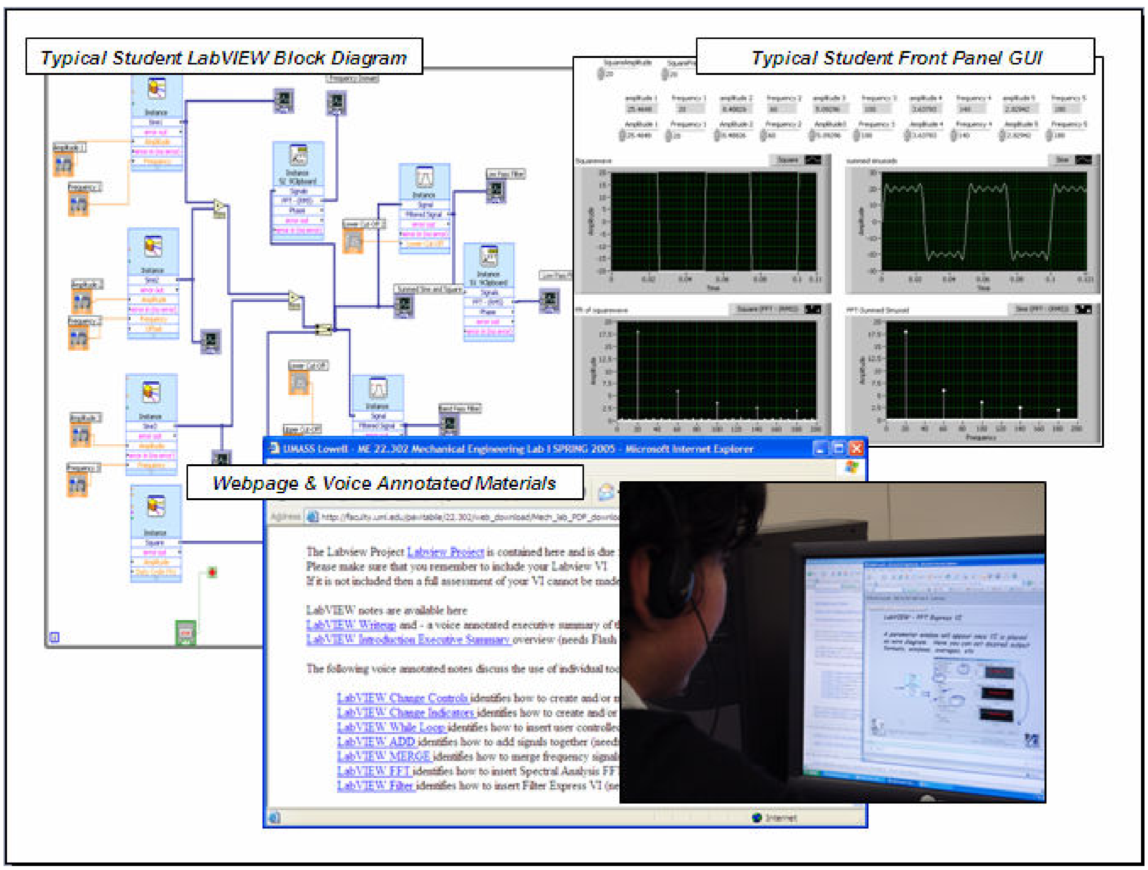


Figure 7 – Overview of Various Aspects of Fourier Series Project

9 – PROJECT: DYNAMIC SYSTEMS PROJECT IMPLEMENTED

A Dynamic Systems course is typically taught as a lecture/homework/test format. However, this material can be presented more effectively with an integrated analytical and experimental project. This approach has been implemented and the details of the project are described.

A set of Dynamic System's projects has been developed to task the students, working either individually or in teams, to address several dynamic system characteristics. The first project is an individual effort, forcing the students to develop the necessary skills to solve systems described by differential equations, Laplace transforms and numerical techniques; this project is a hands-on based analytical project. The second project is a group effort and involves the identification of the mass, damping and stiffness characteristics of a simple second order mechanical system; this laboratory based project clearly helps the students develop intuitive skills necessary to address real world problems. The third project is a group effort and is generally some variation of a theme to extend the material developed in the first two projects; this project usually involves some integrated aspect of the first two projects that gives closure to the material. This last project has included filter characterization, development of techniques to reduce noisy signals, and related issues. The first two projects are described in detail in the next sections.

9.1 - Analytical Modeling Tools for Identification of a Second Order MCK System

The students are instructed to develop generic models to address the response of a second order mass, spring, dashpot system using analytical closed form solutions by both ordinary differential equations and Laplace transformation techniques; these solutions are to be compared to the solutions obtained from both MATLAB and Simulink. The response of the simple single degree of freedom mechanical mass, spring, dashpot system due to external forces and/or initial conditions of displacement and velocity are to be evaluated.

Obviously, the students should have the ability to develop these models with no problems. However, since all the material needed to develop the theoretical solutions may be a little "rusty", the students struggle to varying degrees depending on their individual level of "rustiness". Now it is well known that students work together to develop these solutions and, in some respects, it is valuable to have students helping each other. This reinforces their ability to understand the material by taking ownership of the process. Of course, the closed form analytical solutions can be compared to the MATLAB and Simulink solutions so that the students have, in essence, "the answer at the back of the book".

Each student is given his/her own individual MCK parameters and individual initial conditions of displacement and velocity. In this manner, each student has a different solution. This forces each student to "take ownership" of the solution to his/her problem. (The student can work with other students, but ultimately each must provide their own particular solution to their system.)

The parameters of each model are very easily handled with private information of each student. The student's social security number (xxx-yy-zzzz) is used to define the mass, damping and stiffness and birth month and day are used for the initial displacement and velocity, respectively, according to Table 1. (Note that the birth month is divided by 10 to provide displacements that are reasonable. Also, note that the SS numbers are rounded up for confidentiality.) These parameters result in an underdamped system but characteristics vary between lightly damped to heavily damped, low frequency to high frequency.

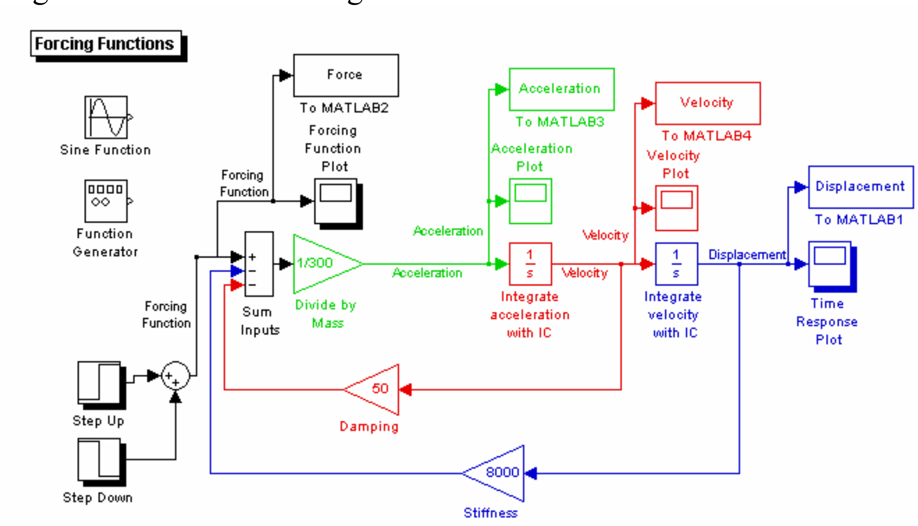
Table 1 – Parameters for Single Degree of Freedom Model

Social Security Number	***xxx***	***yy***	***zzzz***
System Characteristics	Mass	Damping	Stiffness
Birth month and birthday	***month***	***day***	
Initial displacement	month/10		
Initial velocity		day	

For example, SS 123-45-6789 with birthday of Feb 29th results in a model of

$200\ddot{x} + 50\dot{x} + 7000x = f(t) \quad ; \quad x(0) = 0.2 \text{ inch and } \dot{x}(0) = 29 \text{in/sec}$

Working individually, the students reinforce their skills in basic mathematical techniques learned in earlier courses. In addition, new skills are developed to assemble both MATLAB and Simulink models to address any type of first and second order model. The students develop Simulink models that are useful for the solution of many dynamic system responses due to various loading situations as seen in Figure 8.



Simulink model block diagram for single degree of freedom mass, spring, dashpot system with unit impulse input.

Figure 8 – Typical Generic Simulink Model Developed

9.2 - Evaluation of RUBE - Second Order MCK System

The second project utilizes the analytical tools developed in the first project. The students work in groups of three or four members and address the measured response of a mechanical second order system. The students are asked to measure the displacement and acceleration response of a mass-spring-dashpot system. An overview schematic of the RUBE (Response Under Basic Excitation) mechanical system is shown in Figure 4.

The system is available as an online experiment. Students have access to the experiment over the internet using a LabVIEW web-based Interface. A photo of the system and a screen capture of the LabVIEW interface is shown in Figure 5. The important features regarding the RUBE system were presented in the previous section. Every time the system is accessed, the system parameters are changed.

Specific information regarding the system is presented to the students in a set of documents. This forces the students to think about "what IS the actual mass, damping and stiffness of the system?" – rather than being spoon-fed the specific values. The students then work through many different scenarios to determine the best set of system characteristics to describe the overall system characteristics.

The students work with their data and try various approaches to describe the system based on different assumptions and starting points. For instance, they could assume the mass is known/calculated, measure the frequency and calculate the stiffness. The students often only take the minimum number of steps to find a solution. However, many forget to proceed further to check to make sure that the solution obtained is reasonable (is the assumed mass reasonable? -or- how could that little spring possibly be 40,000 lb/in?). While the results of the natural frequency may compare, the physical characteristics of the system may not be believable.

9.3 - Filter Design of RUBE Measured Data - Second Order MCK System

This third project generally requires the students to design a simple filter in Simulink or to build an RC circuit to filter the noisy data that has plagued all of their earlier efforts to numerically process their measured data. At this point in the Dynamic System course, they have been exposed to a sufficient amount of material to be able to design a filter to their own specifications to improve the overall measurement system. This project again forces them to think about the filter attenuation characteristics as well as the phase lag that results in their filtered system.

9.4 - Peer Review of Reports

Once the teams develop their group reports, the next step is evaluation of the reports. However, instead of the professor reviewing the reports, each report is anonymously given to another team to review. Each team must give a sincere, critical evaluation of the report assigned to them. Written comments are then orally discussed with the group. This effort is multi-faceted and has numerous benefits.

The students get first-hand experience in reviewing reports and determining adequacy of the report and material presented. Since each team has just evaluated a similar set of data, they are well equipped to critique the report assigned. Since all groups may not have necessarily used identical approaches for assessment of their systems, the groups learn alternate technical mechanisms for evaluation of the systems. Each group learns from the experience of this review process.

This review process has been found to be extremely useful for the student learning process as well as a reminder of how important it is to be clear, concise, accurate and to the point in generating technical reports. This review process also serves as an aid to the professor since many errors are pointed out by the review teams in the preliminary evaluations.

9.5 - Concluding Statements on Dynamic Systems Projects

This Dynamic System course has been taught in this manner for the several years now and the student comments have been very positive as to their experiences learned. A separate paper [16] contains more detailed information related to the Dynamic Systems Project described.

10 – PROJECT: DESIGN OF DYNAMIC MEASUREMENTS SYSTEM

A Mechanical Engineering Lab five week mini-project was implemented to design a measurement system for the dynamic response of a beam system. This project has been implemented and the details of the project are described.

In the Mechanical Engineering Department at UMASS Lowell, the laboratory courses are taught in a two semester sequence. The first semester concentrates mainly on basic measurement tools (oscilloscopes, multimeters, digital data acquisition, etc), measuring devices (flow meters, manometers, pressure transducers/gages, pitot tubes, strain gages, thermocouples, accelerometers, LVDTs, etc) and methods for data collection/reduction (regression analysis, curvefitting, numerical processing). The first semester has many different labs which, in general, are intended to get the students exposed to the overall mechanical measurement world. However, there are a few labs which are intended to force the students to work through several difficult issues. The second semester is split into two halves. The first half continues the more structured lab environment but introduces more complicated labs and concepts including Fourier domain processing techniques with FFT analyzers. The second half of the semester concentrates on the student development of a measurement system. The students are given only vague specifications for the overall measurement requirements and they must formulate a measurement system to achieve the require goals. This section addresses one of the final lab projects from the second semester sequence of Mechanical Engineering Laboratory. The project involves the development of a measurement system for the response of a second order dynamic system and is discussed below.

10.1 - Development of a Measurement System for a 2nd Order Dynamic System

The problem is posed as a measurement system to determine the tip response of a simple cantilevered structure. The students are to make measurements on a cantilevered beam structure shown in Figure 9. The students are given general guidelines regarding the measurement system to be developed. The students are required to select three non-collocated different measurement devices from five possible transducers such as LVDT, accelerometer, laser, eddy current probes, and strain gages. They must determine suitable locations for the transducers, identify digital data acquisition (DAQ) requirements, etc. to determine the "best" method to address the problem. Ultimately, they are to predict the dynamic response at the tip of the beam.

Measurements from all three devices must be compared to each other which requires spatial adjustment as well as integration/differentiation of displacement, velocity and acceleration measurements. The use of dynamic system models to determine actual response due to arbitrary loading is required (using MATLAB and/or SIMULINK). The optimization of the parameters (signal type, location, transducer sensitivity, etc) is required to provide the "maximum" signal for the ADC specified for the data acquisition. A full formal report is prepared to document all aspects of the project effort along with a formal presentation.

The students proceed with typical procedural steps to finalize the measurement system. Since an analytical model was developed for the “design” of the measurement system, some validation of the model is necessary. Students often use frequency response measurements to assure that the dynamic characteristics of the beam are correctly modeled. Other issues (noise, drift, bias, etc.) are also addressed in the process of designing the measurement system; students have the necessary tools to address the problem from previous courses.

The goal is to obtain the displacement and acceleration at the tip of the cantilever. The transducers are not located at the same position nor at the end of the beam. The real effort lies in the spatial adjustment and integration/differentiation of the measurements taken. A significant effort is needed to achieve this. The students must realize that material from earlier courses is critical to the overall assessment of the problem.

At the conclusion of the project, the groups present their models, assessments and results which predict the tip displacement and acceleration of cantilever beam. A typical “success” story is shown in Figure 9 which shows the overlay of data from a laser, strain gage and accelerometer used at three different non-collocated locations to predict the tip displacement response. As with the case with the Dynamic Systems project, students struggle to complete the project but have indicated that the pain is well worth the rewards of better understanding the material.

10.2 - Concluding Statements on Design of Measurement System Project

This Mechanical Engineering course has been taught in this manner for over 10 years now and the student comments have been very positive as to their experiences learned in developing a measurement system . A separate paper [17] contains more detailed information related to the Dynamic Systems Project described.

$$2.96E^{-4}\ddot{x} + 4.15E^{-4}\dot{x} + 27.619x$$

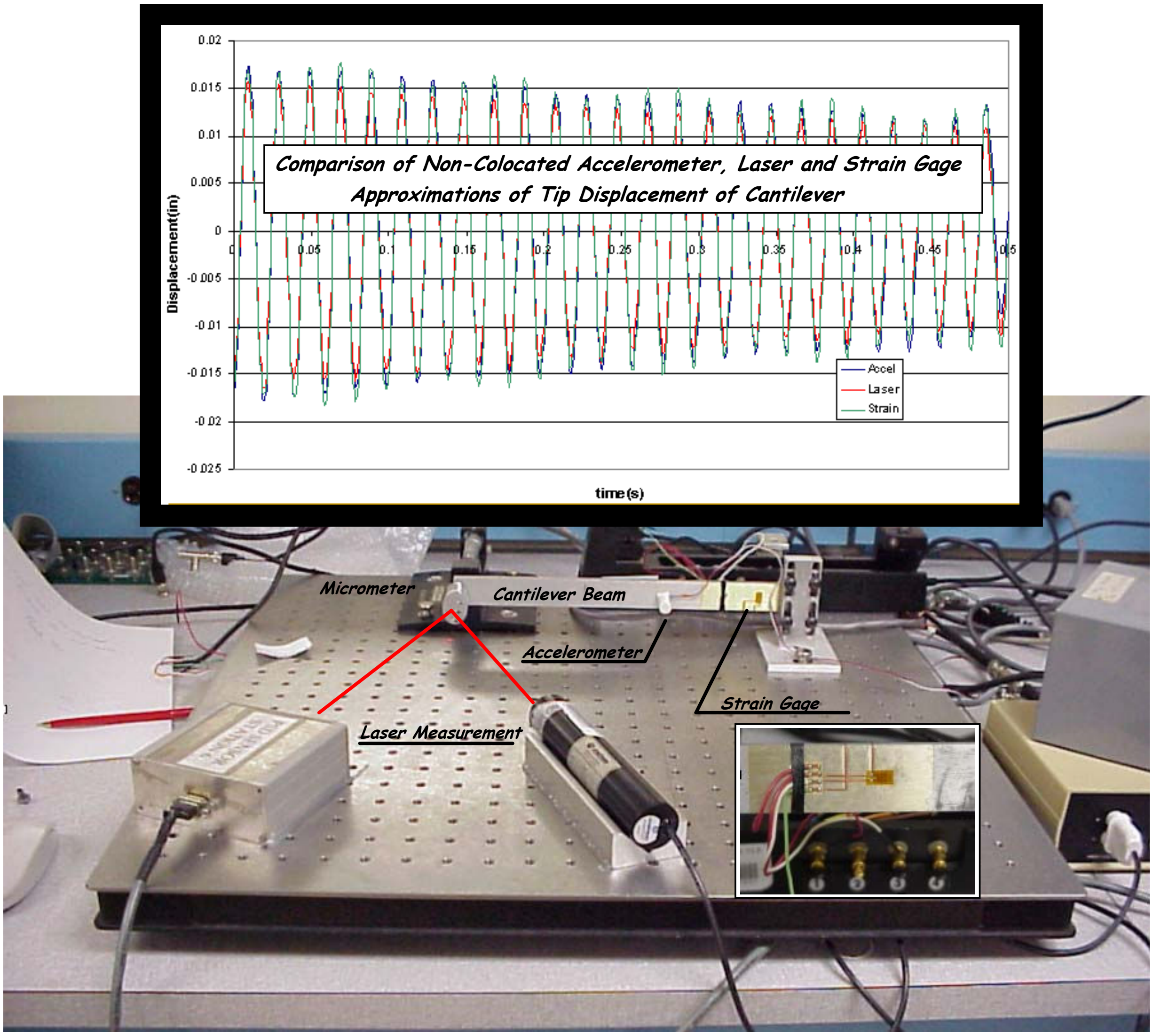


Figure 12 – Comparison of Non-Collocated Accelerometer, Laser and Strain Gage Approximations to the Tip Displacement of the Cantilever

11 - CONCLUSIONS

The curriculum in the Dynamic Systems and Laboratory courses in the Mechanical Engineering Department at the University of Massachusetts Lowell is heavily complemented with hands on projects to foster deeper student learning and comprehension. A wide variety of analytical tools have been developed with Graphical User Interfaces to allow students to explore these topics more deeply. An online measurement system was developed to allow for variable data to be collected for a second order mechanical system.

Several projects were described in this paper and many additional exercises are identified on the DYNSYS webpage (http://dynsys.uml.edu). Two of the more involved projects are described in more detail in this paper. One Dynamic Systems Project is described which utilizes an analytical project complemented with an experimental addition to force student involvement in an open-ended solution to a dynamic system problem. One Mechanical Engineering Laboratory Design of Measurement System project is also described which allows students to be actively involved in the design of an actual measurement system to address a dynamic response problem. Both of these projects are have allowed students to utilize all of their STEM (Science, Technology, Engineering, Math) skills to solve real problems with no clear cut solution to the problem. This approach has had very positive impact on student learning and understanding for possible solution approaches.

12 - ACKNOWLEDGEMENT

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13 - ACKNOWLEDGEMENT – DYNSYS Project - Mechanical Engineering Students

Much of the work associated with this effort to develop materials which better integrate STEM material in the Mechanical Engineering curriculum is a direct result of many students in the University of Massachusetts Lowell program. A special thanks to those students who have really been the driving force in making all this happen. They are (in no particular order) Tracy Van Zandt, Nels Wirkkala, Jeffrey Hodgkins, Charles Wes Goodman, Dana Nicgorski, Adam Butland, Christopher Chipman, Aaron Williams, Tiffini Johnson, Dereck Ouellet, Chris DiNitto. This could not have been done without their dedication and devotion to developing these materials. It has been a pleasure working with them and having them contribute to this effort. All of their efforts are sincerely appreciated.

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APPENDIX A – Detailed Description of Major Analytical Tools Developed

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

First Order Systems – Modeling Step with ODE and Block Diagram

Response of First Order Systems – Step Response, Impulse Response and Free Response – covers basic development of a model for a first order system - a MATLAB script with variable parameter selection via a GUI as well as a LabVIEW VI allows the user to explore parameters other than the specific values used in the tutorial.

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 as well as a LabVIEW VI allows the user to explore parameters other than the specific values used in the tutorial.

Second Order Systems – Modeling Step, Impulse, IC with ODE and Block Diagram

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 as well as a LabVIEW VI allows the user to explore parameters other than the specific values used in the tutorial.

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 other than the specific values used in the tutorial.

Mathematical Modeling Considerations

Fourier Series Tutorial– covers basic concepts of generating a set of Fourier series terms to approximate general waveforms - a Simulink script (as well as a LabVIEW VI) 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 allows the user to easily modify noise contaminants on the signal and view the effects upon integrating or differentiating the data.

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.

Convolution Analysis Tutorial– covers basic concepts of the convolution integral and application to pure mathematical representations of some common waveforms as well as a specific application to a second order mechanical system subjected to an impulse excitation – a Labview GUI allows the user to easily select different mathematical functions to understand convolution concepts by interacting with the integration process to move forward or backward in the numerical process to see the complete development of the resulting computation as well as the individual function relationship during the process.

Simulink and MATLAB Primer Materials – (details of these are self evident from title)

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

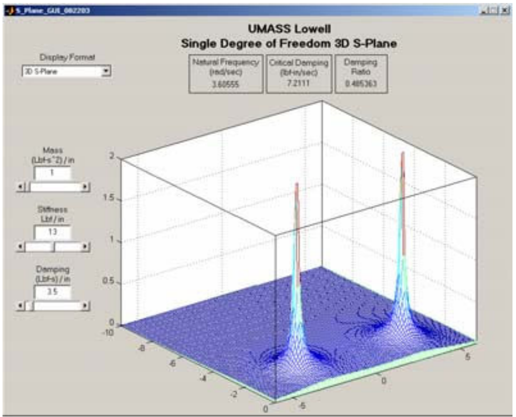
Virtual Measurement System – covers basic concepts of measurements that can be obtained from second order systems – provides a Simulink GUI that allows the user to specify the second order analytical model and then introduce common measurement errors of noise, bias error, drift, offset on the analytical 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.

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.

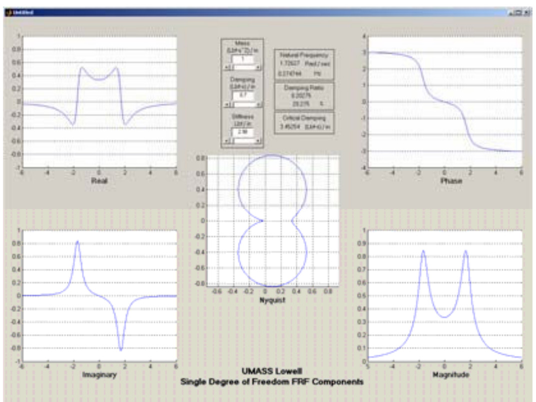
Gravity Driven Flow Simulations – covers basic concepts of flow dynamics for a variety of different tank and exit pipe configurations which includes the solution of an initial value problem that involves a nonlinear relationship between the elevation head that is driving the flow and the instantaneous flow rate out of the tank, A MATLAB GUI is developed to allow the user to select the tank geometry of interest, specify tank dimensions, choose the working fluid, set pressure relationships, and identify many exit pipe details including length, pipe roughness, loss coefficient, etc. The GUI was designed to give insight into complex fluid mechanics characteristics for tank draining problems typical for Chemical Engineering applications.

Sample GUI screen shots for many of the tutorials described above are contained on the following sheets with a brief explanation of the particular GUI features.



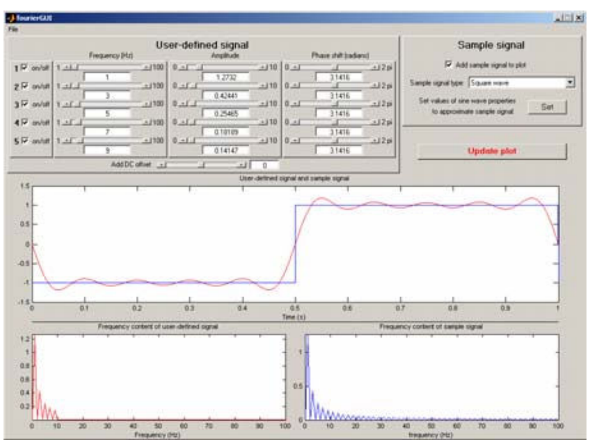
<u>MATLAB - Single DOF 3D S-Plane GUI</u>

User enters M, C, K and natural frequency, critical damping and damping are reported.
User can vary the physical parameters with slide bars. The user can select various 3D transfer function display options of real, imaginary, magnitude, phase and root locus plots.



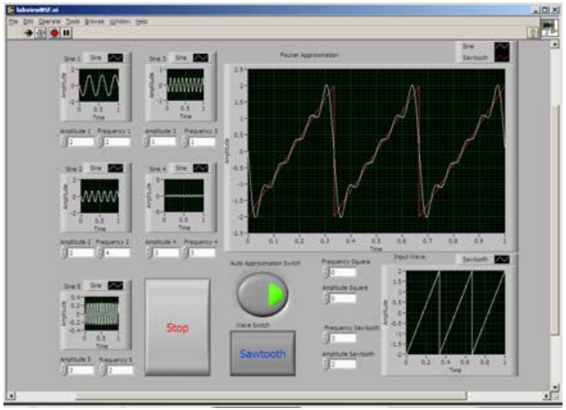
<u>MATLAB - Single DOF Complex FRF Plot GUI</u>

User enters M, C, K and natural frequency, critical damping and damping are reported.
User can vary the physical parameters with slide bars. The complex frequency response function is displayed simultaneously as real, imaginary, magnitude, phase and nyquist plots.



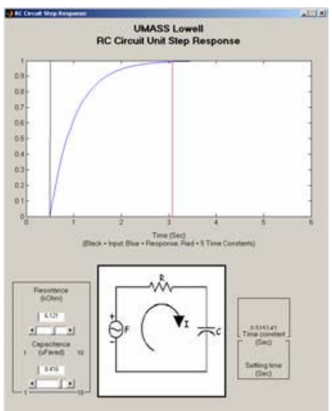
<u>MATLAB - Fourier Series Signal Generation GUI</u>

User enters frequency, amplitude and phase components of a user defined signal to display the resulting signal. 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.



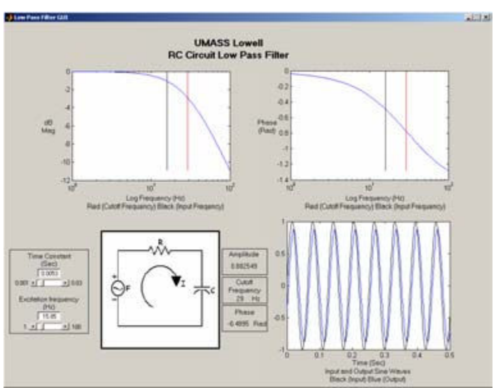
Labview - Fourier Series Signal Generation GUI

User enters frequency, amplitude and phase components of a user defined signal to display the resulting signal. 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.



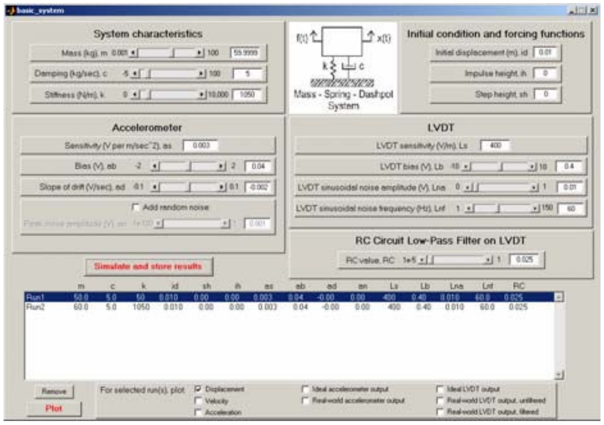
MATLAB - First Order Step Function GUI

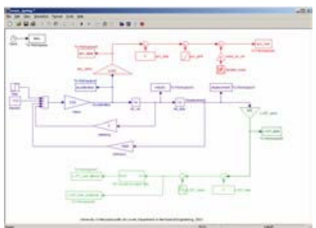
User enters resistance and capacitance values to observe the time response due to a step function. The time response is displayed showing the rise to the step value.

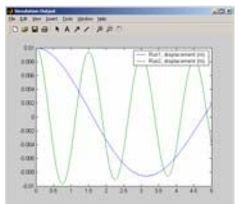


MATLAB - First Order Low Pass Filter GUI

User enters time constant and sinusoidal frequency. The Bode plot is displayed with the cutoff frequency and the sinusoidal frequency applied. The initial sinusoidal signal and “filtered” time signal are also displayed.

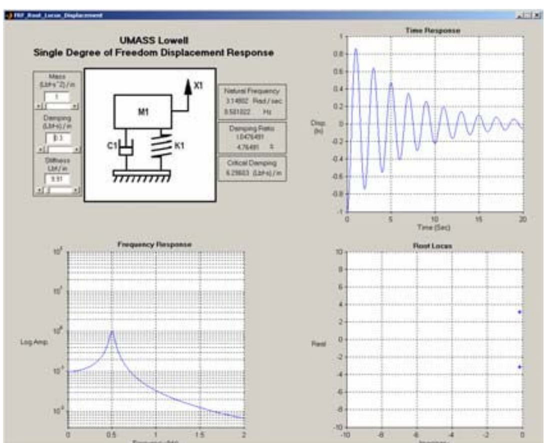






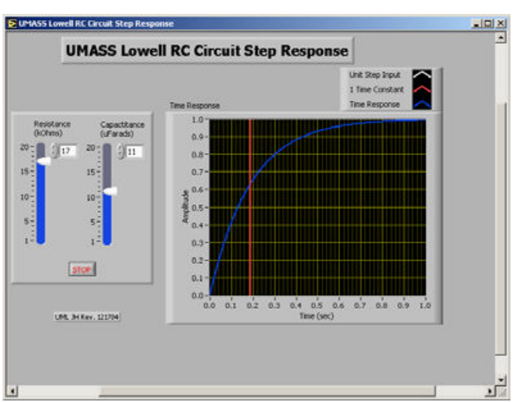
<u>MATLAB/Simulink - Virtual Representation of an Actual Measurement System GUI</u>

User enters M, C, K system. User enters the amount of experimental distortion on the accelerometer (sensitivity, bias, drift) and displacement LVDT (sensitivity, bias, noise) and the low pass filter characteristics to virtually “simulate” the measurement environment. Data can be exported with ability to select which outputs and what effects are included on the measurement.



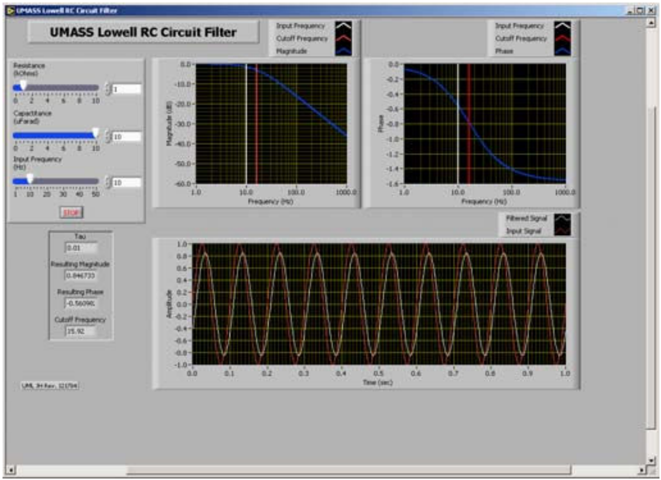
<u>MATLAB - Second Order System Initial Condition Response GUI</u>
User enters M, C, K and natural frequency, critical damping and damping are reported.
User can vary the physical parameters with slide bars. The frequency response function magnitude is displayed root locus and time response.

<u>MATLAB - Second Order System Impulse Response GUI (not shown)</u>
(similar to GUI above)
<u>MATLAB - Second Order System Step Response GUI (not shown)</u>
(similar to GUI above



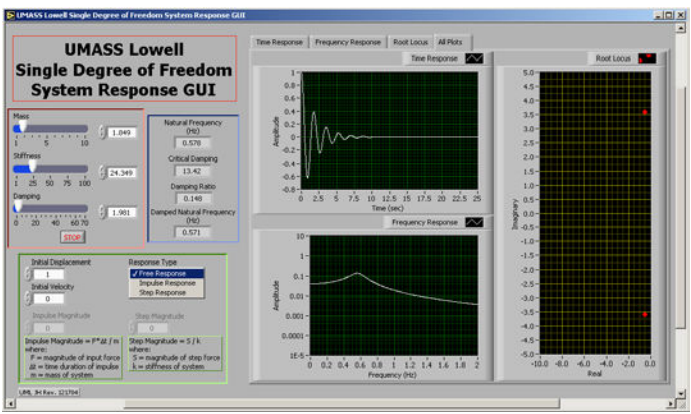
<u>LabVIEW - First Order Step Response GUI</u>

User enters resistance and capacitance values to observe the time response due to a step function. The time response is displayed showing the rise to the step value.



LabVIEW - First Order Low Pass Filter GUI

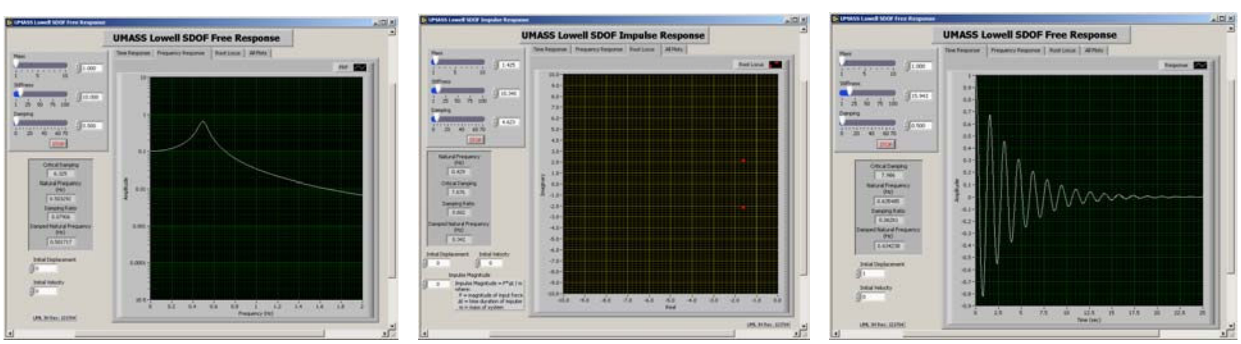
User enters the resistance and capacitance to identify a time constant along with an input sinusoidal frequency. The Bode plot is displayed with the cutoff frequency and the sinusoidal frequency applied. The initial sinusoidal signal and “filtered” time signal are also displayed. The GUI reports the time constant and related magnitude and phase of the signal. The GUI allows for adjustment of the parameters with updating of all plotted and reported data to give the user quick visual information regarding the system characteristics.



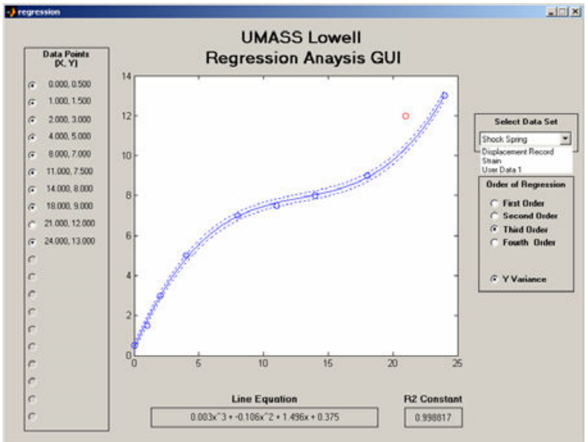
LabVIEW - Second Order System Response GUI

User enters M, C, K and natural frequency, critical damping and damping are reported. User can vary the physical parameters with slide bars. User can also specify response type for free response, impulse or step along with initial conditions. The frequency response function magnitude is displayed along with the root locus and time response either as individual plots or all three plots displayed simultaneously (as shown).

LabVIEW - Second Order System Response GUI – Step, Impulse, Free



Similar to the GUI above but each response in its own GUI

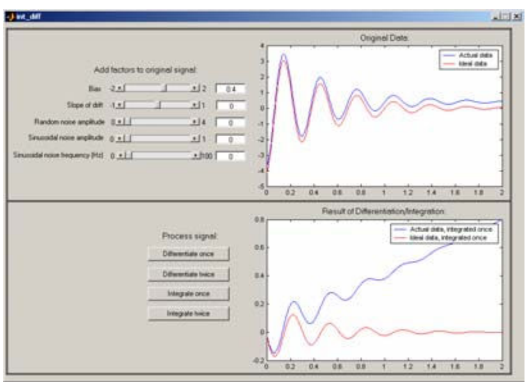


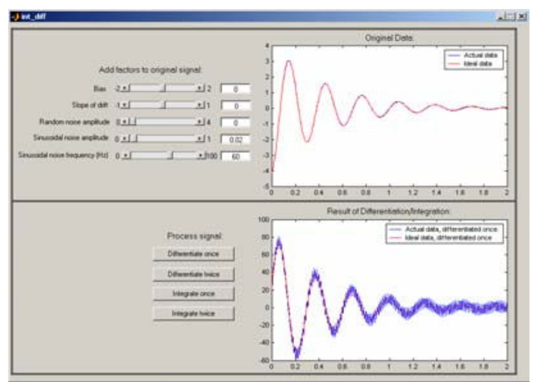
MATLAB – Regression Analysis GUI

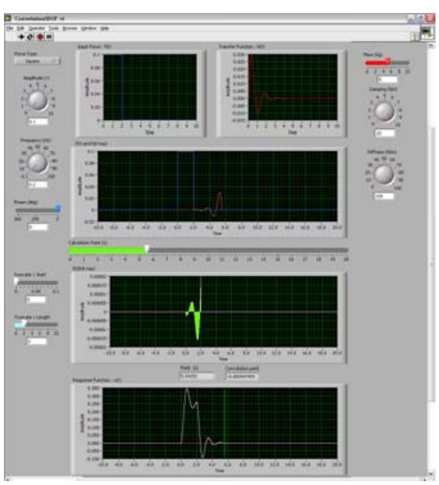
User can take existing data representing several typical types of data found and select the order of the regression, inclusion of y variance and manually select and deselect individual data points to be used for the regression analysis. The GUI reports the equation of the best fit line based on the parameters selection along with the regression coefficient. The user is also allowed to create personal data sets for inclusion in the GUI.

MATLAB – Integration/Differentiation GUI

User enters a variety of different noise contaminants (bias, drift, random noise, sinusoidal noise) onto a damped exponential sine wave. The signal can then be processed using either differentiation or integration of the signal (once or twice applied) and the results observed.







Labview – Convolution Integral Simulation GUI

Two variations of this GUI exist. Considering the convolution for a second order mechanical system, the user enters system characteristics such as mass, damping and stiffness for the characteristic function and then can observe the response due to an impulse function. The GUI allows the user to take complete control of the development of the entire convolution function computation with a scroll bar to parade forward or backward to any particular time of the numerical process. (An alternate variation of the GUI is set up for pure mathematical representation of arbitrary signals to show the convolution integral from a mathematical prospective.)