# 2006-1919: IMPLEMENTATION OF SOME DYNAMIC SYSTEMS MATERIAL INTO THE MECHANICAL ENGINEERING CURRICULUM

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# Implementation of Some Dynamic Systems Material into the Mechanical Engineering Curriculum

## Introduction

In today's engineering education environment it is important to provide students with educational material that will enhance or supplement their learning process. It is obvious that the multimedia and internet capabilities available today, provide a tremendous opportunity for innovative learning pedagogy. An example of this innovation is a new multisemester interwoven dynamic systems project that has been developed by UMass-Lowell through a grant from NSF. The project goal is to better integrate material from differential equations, mathematical methods, laboratory measurements and dynamic systems across several semesters/courses. This should enable students to better understand the relationship of basic STEM (Science, Technology, Engineering, and Mathematics) material to an ongoing problem[1,2,3,4].

Dynamic modeling and testing of mechanical systems provides students with important understanding of the characteristics and performance of structural dynamic systems. Student comprehension of this important Mechanical Engineering topic in today's world of simulation, instead of testing, is critical. The materials from UMass-Lowell are adapted and implemented into three of the Mechanical Engineering curriculum courses at Michigan Tech. The materials were interwoven into the existing course material to enhance the student's understanding of measurement systems, and basic first and second order systems. Use of existing graphical user interface (GUI) materials should help the students to better comprehend confusing concepts and ideas. Use of an online data acquisition system for a second order mechanical system serves as a companion to a conventional lab experiment and further enhances their learning. Student assessment indicates that the materials improved the student's level of knowledge. This paper documents the implementation and use of this material in several courses offered by the Mechanical Engineering program at Michigan Technological University.

## Initial NSF Project

A new multisemester interwoven dynamic systems project under the leadership of faculty at UMass-Lowell has been in progress for the last two years. 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 third phase of this project is to implement and adapt this material into the curriculum at another institution, in this case the Mechanical Engineering curriculum at Michigan Technological University. This phase of the project grew out of a long standing relationshsip between faculty at each University. These collegues have worked together for more than twenty years, developing educational material for seminars and short courses.

**Michigan Tech Dynamic Systems Courses**

The dynamic systems portion of the curriculum at Michigan Technological University consists of three required core courses in conventional dynamics, mechanical vibrations and control systems. In addition to these courses, there are several senior elective classes and a required mechanical engineering laboratory course, which reinforces concepts that are presented in dynamics, mechanics of materials, and heat transfer. The material developed as part of the UMass-Lowell project was interwoven into three of these courses: mechanical vibrations, mechanical engineering laboratory, and a senior elective class in experimental and analytical modal analysis (advanced vibrations). The material was used as developed by the team at UMass Lowell. No modifications were considered during the first semester's use of the material. Modifications, and development of additional material will be considered based on faculty feedback and student assessment.

**Mechanical Vibrations Course**

In the mechanical vibrations course, a tutorial and Matlab GUI on Fourier series was implemented to help the students in their understanding of frequency domain concepts. Students were asked to obtain the tutorial material and Matlab code from the project's web site (http://dynsys.uml.edu) . Students were assigned this as part of their regular homework for the class after a lecture on Fourier series and frequency domain concepts. Additionally they were asked to comment on their experience with the material, specifically with respect to whether or not, their understanding of Fourier series and frequency domain concepts was improved through this exercise.

The Fourier series material consists of a tutorial which describes the concepts and mathematics of the Fourier series, along with a Matlab GUI, Figure 1, which is based on a SIMULINK model, Figure 2. The GUI allows the user to visualize waveforms by adding up to five frequency components by describing their frequency , amplitude, and phase. Once these components are selected, the GUI displays both time and frequency domain representations of the resulting waveform. The user can adjust the Fourier series coefficients and immediately see the effect of this adjustment on the time domain waveform.

The specific assignment consisted of several parts, which helped helped the student gain an understanding of time vs. frequency domain waveform visulation and concepts of Fourier series analysis. The tutorial which accompanies the GUI describes how to create a square wave signal using appropriate sine wave components. Once an understanding of the GUI operation is accomplished, the user is encouraged to determine (using the GUI) the sine wave components (frequency, amplitude, phase) which make up other common periodic waveforms such as sawtooth, triangular, etc. Besides completing the tutorial and exercising the Matlab GUI, students were asked to comment on the material, as to whether or not it was helpful in enhancing their understanding of Fourier series concepts. 83% of the students had favorable responses, as well as some ideas for improving the tutorial and GUI material. A typical favorable response:

> *"this assignment helped illustrate that the combinations of signals, whether constructive or destructive, can be very useful in the approximation of desired signals. The use of this*

*Matlab program is much easier than calculating all of the approximations by hand through the use of mathematical methods. I also noticed that the frequency domain is helpful to analyze signal combinations. Small variations can go unnoticed in a simple time domain plot of the signals, the frequency domain shows that these small frequencies have an effect and when closely analyzed can be observed and then accounted for* ".

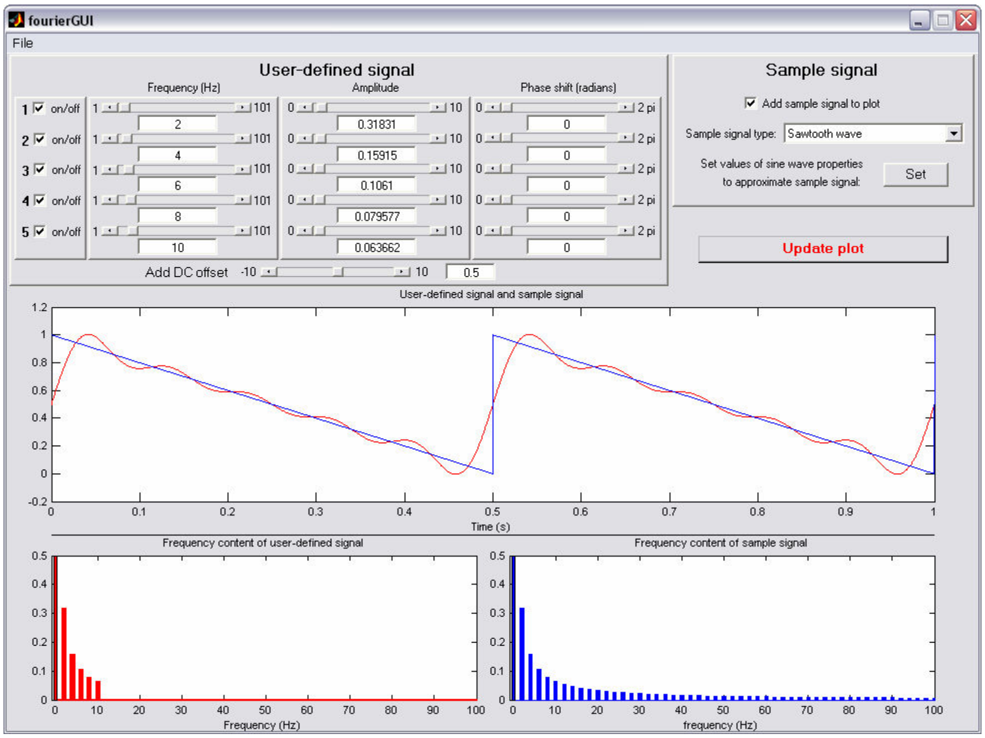



**Figure 1 Matlab Fourier Series GUI**

A typical unfavorable response:

*"I really didn't learn anything from the Matlab programming. It was nice seeing a visual of the waves, but the slides in class already showed us this. I don't understand what the plots at bottom were trying to represent since there was no label on the y-axis."*

Almost all of the students had suggestions for improvements in the tutorial and the Matlab GUI. These suggestions will be reviewed and used to improve the material.

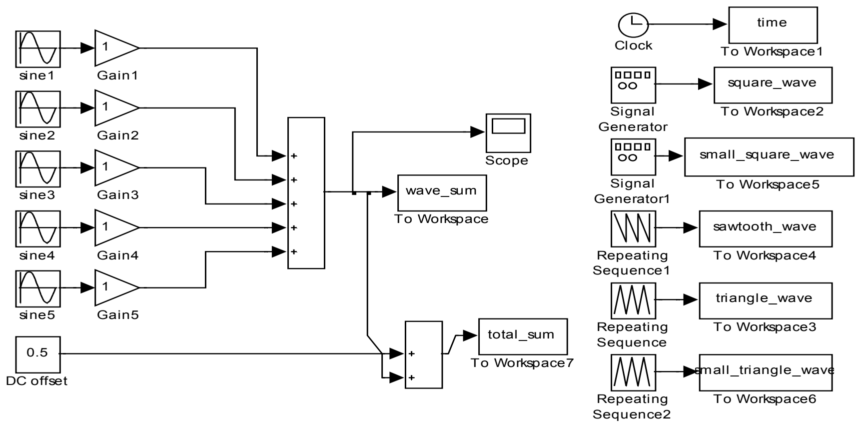



**Figure 2 Simulink Model of Fourier Series**

**Mechanical Engineering Laboratory.**

As part of MTU's curriculum review in 2000, a new (required) laboratory course for mechanical engineers was developed[5]. Students who successfully complete the course have obtained laboratory skills in the measurement and analysis of static and dynamic phenomenon related to typical Mechanical Engineering topics. During the first three weeks of the course all students participate in laboratories introducing the basic concepts of measurement systems, digital data acquisition, and transducers and calibration. Fifteen stations are available which consist of a networked PC, a Digital Data Acquisition system, an Oscilloscope, signal conditioning, and transducers. The remainder of the course consists of lectures and experiments that reinforce concepts presented in Dynamics, Mechanics of Materials, Thermal Sciences, and Dynamics Systems. Students work in assigned teams producing written reports that present the mechanics of the experiment as well as conclusions drawn from the measured data.

One of the items that was developed as part of this project is an "on-line" data acquisition system. This online experiment allows the user to collect data on the motion of a second-order mass-spring-dashpot system, Figure 3 . The theoretical aspects of this system are covered in the Mechanical Vibrations course mentioned above. These courses are taken as corequisites in MTU's Mechanical Engineering curriculum.

The properties of the system vary with time—the moving mass of the system includes a small water tank which fills and gradually drains, and the spring portion of the system includes a leaf spring which changes in length each time the system is activated. In addition, three different initial displacements are available as inputs to the system. Consequently, each user of the system will obtain slightly different results.

Multiple different transducers are used to collect acceleration and displacement data on the motion of the system. Good transducers are available, which provide relatively clean data. However, "bad" transducers—contaminated by noise, drift, or bias—are also used. The user can therefore gain experience processing less-than-perfect data and better understand the importance of good measurements.

Data can be acquired from the system in two ways. The system can be controlled live and the data collected and saved. Only one person may use this feature at a time. Alternatively, the user may obtain a randomly selected data set that has been previously collected. A typical set of data (free vibration response) from each of the system's 4 motion transducers is shown in Figure 4.

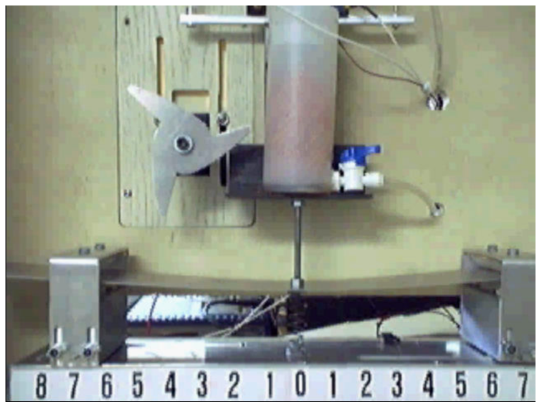



**Figure 3 "On-Line" Experiment**

This experiment was used in the mechanical engineering laboratory course to enhance students understanding of free vibration response and the use of measurement transducers in a digital data acquisition environment. For purposes of assessment students were divided into three groups, each group consisting of about 40 students. Group 1 was assigned the online experiment as part of a mid-term examination. Students were given full credit for any reasonable attempt at completing the experiment. These students were used to verify proper operation of the experiment over the Internet. Students belonging to Group 2 to were assigned the on-line experiment in place of one of the regular hands-on dynamic systems experiments. They completed the assignment with their regular lab groups and submitted a normal lab report describing the results of the experiment. The third group of students were not exposed to this online experiment. These students were used as a control group in the assessment of this experiment.

As with the Fourier Series material, about 80% of the students responded favorabily to this experiment. Most of the students expressed caution however, stating:, *"on-line experiments can never and should never completely replace the experience one has with a real hands-on laboratory experiment"*. The student suggestions for improvement to the material are being reviewed and will be used to improve the experience for future users.

Because of the large number of students in mechanical engineering laboratory class (130), an attempt was made to assess the effect of using this material. This was accomplished by including a question on the final exam that specifically addressed one of the major topics that was covered in the online experiment. The experiment was designed to show the students not only the measurement of a structure's free vibration response, but also how this response can be observed by four different motion transducers. One of the four motion transducers, an accelerometer, was sized correctly and processed correctly to give a close to ideal measurement of the motion. Each of the other three transducers suffered from some sort of measurement error. One measurement signal had an overload, one had a quantization error, and one had extraneous

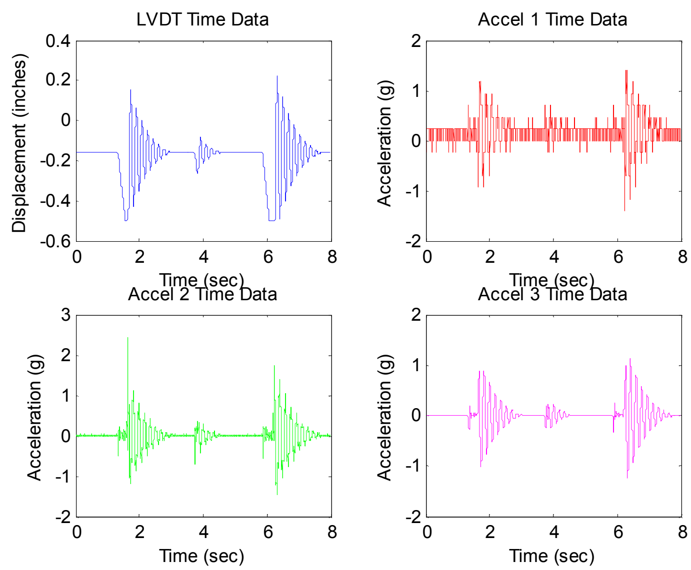



**Figure 4 Data Produced by the Online Experiment**

noise on the signal. These types of measurement error and transducer conditions were discussed in the second and third week of the course and were highlighted in laboratory exercises at that time. Too often students do not experience “poor or bad” data. This experiment is designed to address that deficiency.

To assess the value of the online experiment material a question was placed on the final exam for Groups 2 and 3. Group 1 students were not asked this question. The question is as follows:

1. The time history shown, Figure 5, below was obtained from a Siglab data acquisition system with a bandwidth of 1000 Hz. The input range was set to its maximum value. *Which of the following statements is most correct?*
   a. The signal has an aliasing error
   b. The signal has a DC(+) offset
   c. The signal has a DC(-) offset
   d. The signal has quantization error
   e. a and b
   f. a and c
   g. c and d
   h. b and c
   i. b and d

The answer to this question is "g.", the signal suffers from quantization error are as well as having a negative DC offset. The answers to this question were compiled for both Group 2, those who performed the online laboratory experiment, and Group 3 those who did not see this experiment. Their answers are shown in Figure 6.

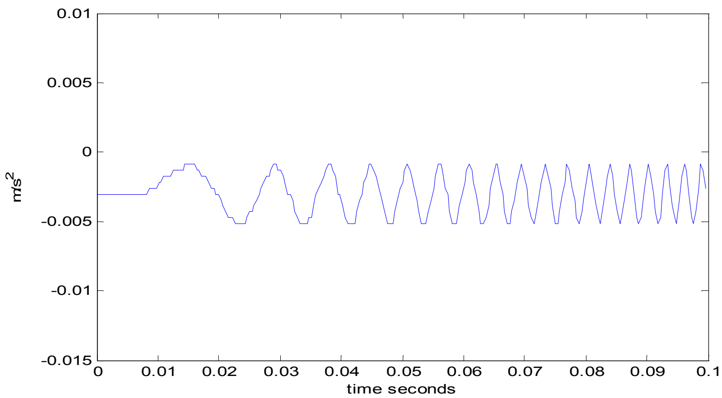
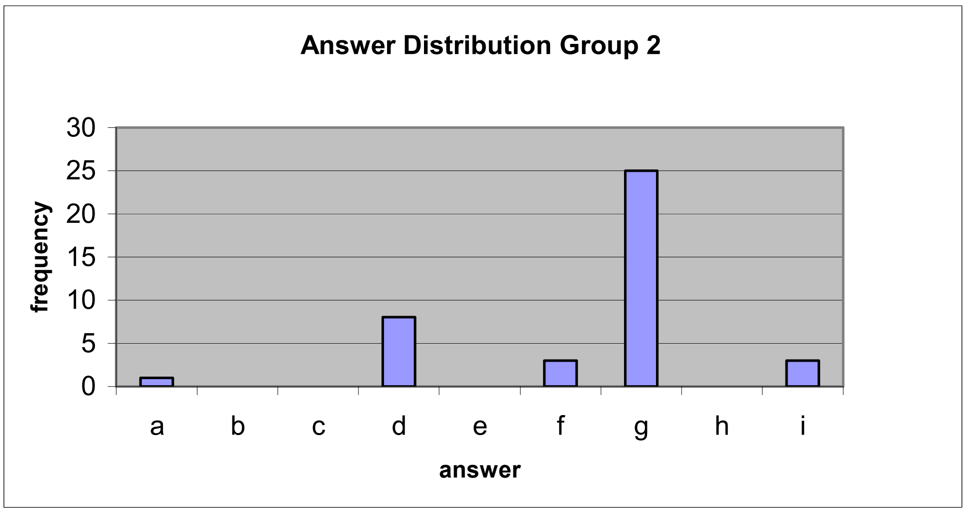



**Figure 5 Data for Assesment Question**



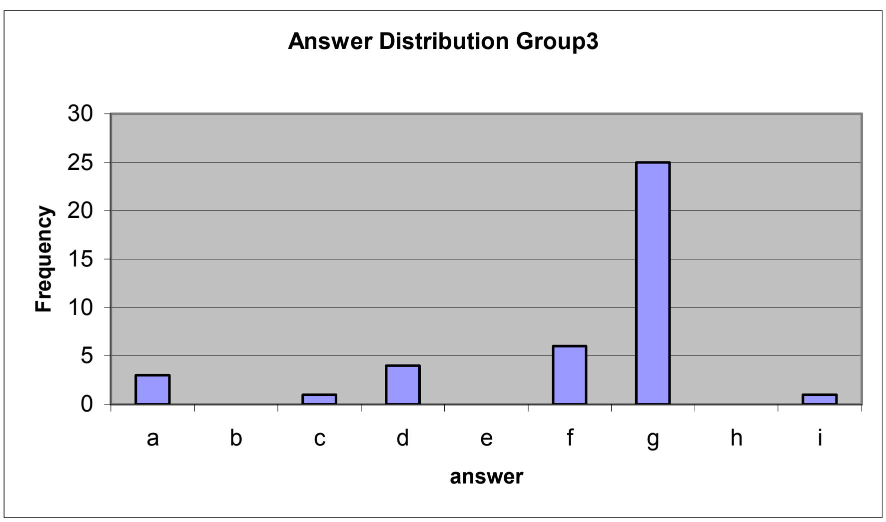




**Figure 6 Distribution of Answers to Assesment Question**

Each group consisted of 40 students. As can be seen from Figure 6, a total of 25 students correctly answered the question in each of the groups. The interesting fact from the data shown in Figure 6 is that a larger number of students answered. "d" in group 2 than in group 3. This is noteworthy because answer "d" is a correct answer. The signal does suffer from a quantization error. However, it is not the most correct answer. This data seems to be consistent with the comments made by the students on the usefulness of performing this online experiment. As stated earlier experiment was received favorably however, a majority of the students describe the experience as a good review of their understanding of measurement transducers and digital data acquisition concepts. Only a few of the students commented that this online experiment helped clarify their understanding of the material.

## Conclusions

Dynamic modeling and testing of mechanical systems provides students with important understanding of the characteristics and performance of structural dynamic systems. Student comprehension of this important Mechanical Engineering topic in today's world of simulation, instead of testing, is critical. Materials from an existing NSF funded project are adapted and implemented into three of the Mechanical Engineering Department curriculum courses. The materials were interwoven into the existing course material to augment the student's understanding of measurement systems, and basic first and second order systems. Use of existing graphical user interface (GUI) materials helped the students to better comprehend confusing concepts and ideas. Use of an online data acquisition system for a second order mechanical system served as a companion to a conventional lab experiment and "was a good review" as indicated by their comments and feedback on the assignment. Student assessment of the assignment using an exam question indicated inconclusive results. These results will be used to refine the online experiment and improve its effectiveness.

## Acknowledgement

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