Integration of Hands-on Experience into Dynamics Systems Teaching

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Abstract

With the advent of significant developments in technology the process of product development is undergoing remarkable changes. Companies now require engineers who understand broader multi-disciplinary systems and their working. Kettering University is currently engaged in reforming its curriculum to meet some of these demands. The objective of this paper is to discuss two new core courses that were developed in the Department of Mechanical Engineering in the area of multi-disciplinary dynamic systems in order to reach this goal. The idea is to teach these courses using a unified approach to systems, with hands-on laboratory experience and system simulation using software tools like MATLAB®, and focusing on an inquiry-based problem-driven approach. This is a team effort and a number of faculty members from the ME Department will be involved in executing this project. Upon completion of these courses, the students should be able to demonstrate a good understanding of design, modeling, simulation, analysis, and identification of multi-disciplinary engineering systems.

This paper describes how the courses are laid out in order to achieve the desired goals and how the laboratory experiments should fit into the courses to promote this multidisciplinary understanding.

Introduction

Kettering University, formerly known as GMI Engineering & Management Institute, offers Bachelors Degree programs in Mechanical, Electrical, Computer, Industrial and Manufacturing Systems Engineering, Environmental Chemistry, Applied Mathematics, and Management. Kettering students begin a unique five year cooperative education program in their freshmen year by alternating 12 week period of classroom studies with related work experience in over 600 corporate affiliates. The Kettering Mechanical Engineering (ME) Department has an enrollment of
1300 students, one of the largest in the country. For the past 75 years, Kettering University and the former GMI strive to provide its students with top quality class room instructions, state-of-the-art laboratory facilities and career oriented work-experience in industry.

The corporate sponsors of Kettering students include US Army, Auto makers-General Motors, Ford and Daimler-Chrysler, Aircraft companies and their suppliers such as United Technology, Moog, Vickers-Airequip, Computer manufacturer IBM, Appliance manufacturer Whirlpool and over 600 other companies. As can be seen, the companies that sponsor Kettering students represent a diverse cross section of US industries. The changes that have been taking place in these industries, their need and the challenges faced by them are immediately reflected in Kettering University’s classrooms as these students bring valuable experience after 24 weeks of work experience per year with their corporate sponsor.

Description of the problem

The Mechanical Engineering Department of Kettering University is committed to a large-scale change in its entire curriculum. We plan to move from a content-intensive, faculty-centered way of delivering information and skills to a problem-driven, inquiry-based approach with embedded assessments of student’s outcomes throughout a series of integrated courses. A new set of integrated core curriculum is planned which emphasizes the development in stages of specific learning skills such as critical thinking and collaboration between students and instructors in an active mode of learning. The integration of a knowledge set involving dynamics, vibration, system modeling and analysis, and control systems is the subject of this text. It is believed that this integrated experience will culminate in an integrated capstone or specialty experience in which the students will apply their knowledge and work in groups to solve specific problems. The modifications that are planned involve significant changes in pedagogy and the level of student involvement. This will involve the entire faculty team currently teaching these courses and impact our entire Mechanical Engineering student body.

This paper addresses the major step of adapting successful strategies in the design, implementation, and evaluation of two new core course experiences, and is an outgrowth of a few years of planning. We have established a timeline to phase out the old courses and to pilot each new core course to a typical class. This will enhance and revitalize the undergraduate Mechanical Engineering Dynamic Systems curriculum at Kettering University by bringing in a multi-discipline integrated laboratory and simulation experience.

Not long ago, automobiles, for instance, were primarily mechanical products with limited electrical and electronic applications. Today, a microprocessor-controlled engine control system monitors the engine exhaust to establish proper air-fuel ratio, ignition timing etc. to run the engine optimally. Other applications in automobiles include ABS brakes, traction control systems, and electronic stability control system to name a few. This trend in integrating different disciplines can be observed in washers, dryers, audio/video equipment, exercise machines, modern machine tools, computer drives, lawn mowers, and aircraft. A large number of ME students and students from other Kettering University departments are required to work on products involving multi
disciplines. Thus in order to keep in pace with changes in technology, Kettering University is developing this multi-and-inter disciplinary core courses at the ME Department.

A group of faculty currently teaching the afore-listed courses (vibration, systems analysis and control systems) at Kettering University is involved in the task of enhancing this curriculum. This project is based on the Design Clinic approach practiced at Harvey Mudd college, Claremont, CA., and uses this as a model with suitable modifications. At the design clinic the students take a single engineering system and go over the process of modeling, simulation, analysis and performance improvement using computer simulation and hardware building. In our model, the scope of the problem is reduced and handles more number of problems introducing variety and flexibility. The central theme hands-on approach remains unaltered.

Funding is being pursued for purchasing laboratory hardware, computers, software packages and related interface components. One of the main features of this laboratory is seamless integration of data logging, analysis and modeling packages both in time and frequency domains using off-the-shelf software packages. This laboratory will have optimum blend of concepts, emphasizing multi-disciplinary nature of engineering systems, from mechanical, thermal, electrical, electronics, computers, hydraulic, pneumatic, and acoustic technologies.

A complete set of new laboratory experiments in multi-disciplinary area encompassing various applications is being developed. These experiments are designed to provide hands-on experience to real world problems and typically contain several distinct technologies.

The instruction part of the courses will be application-independent, to model, analyze, identify and synthesize multi-disciplinary systems. The approach will emphasize the commonality present in different systems and the interface between them. The students will be required/encouraged to investigate different applications. The experiments will be designed to reinforce the concepts covered in the lecture.

Goals and objectives

An understanding and appreciation of multi-disciplinary engineering systems is demanded of current graduates by a number of employers including the big-three automakers. Input from graduating students indicates that lack of hands-on laboratory experience is a major handicap in understanding multi-disciplinary systems. Therefore the objective here is to develop and teach a set of core courses in multi-disciplinary engineering systems including hands-on laboratory experience for undergraduate engineering students. Initially two courses are planned with four hours of lecture and two hours of laboratory each week for one term. The goals to be reached are the development of the following:

- Course material and a laboratory manual.
- A unified approach to teach multi-discipline engineering systems as a combination of various engineering disciplines.
- A set of experiments for the Dynamic Systems laboratory.
- A set of engineering applications/problems to teach modeling, simulation, identification.
and design of multi-disciplinary engineering systems among undergraduate mechanical engineering students.

- Multi-disciplinary skills among mechanical engineering students, desired by corporate sponsors.

Considering the tasks involved in the development of such courses, a joint effort of a number of faculty members is required and it is anticipated that help from other departments such as Electrical and Computer Engineering will be sought when needed.

The Mechanical Engineering Department and Kettering University are strongly committed to curriculum improvements through innovation and laboratory development. Currently the courses in dynamic systems stream prepares students for different specialties through traditional classroom lecture methods. This approach can be changed. The emphasis will be on active learning and critical thinking. The students will be encouraged to examine various alternate solutions using computer simulation approach and verify some of them by performing experiments in the laboratory and report their findings. This will allow motivated students to engage in challenging problems well beyond normal curriculum. The laboratory will offer a wide variety of experiences in multi-disciplinary areas including modern method of controlling, collecting and analyzing data using computers.

The material for these courses will consist of a well-balanced blend of engineering disciplines, mechanical, electrical, thermal, hydraulic, pneumatic, electronic and computer technology. These courses are primarily aimed at junior and senior level mechanical engineering students (it is expected that the students have taken the necessary pre-requisite courses). While the details of coverage of these courses are being worked out, the course material is expected to cover design, applications of differential equations, electrical machines, analog and digital electronics, transducers, modeling, analysis techniques, actuators, hydraulics and pneumatics, microprocessors and programming.

**The courses: Dynamic Systems I and II**

A list of subjects that are going to be covered by the courses follows (see Appendix A and B).

Fundamental concepts in modeling; Lumped element modeling; Unified modeling bond graph \[^{2,3}\] approach; Development of state space equations for different systems-including mechanical, electrical and multi-disciplinary systems; Response prediction of systems using classical and simulation techniques-time and frequency domain responses of first and higher order systems; Understanding system behavior including effect of feedback; stability and steady-state performance; Design methodology for controllers to improve system performance; Real world applications related to system modeling, analysis and controller design and implementation using a microprocessor.

Fundamental concepts of vibrating systems; Analogy between mechanical, electrical, hydraulic and pneumatic system behavior; Behavior characterization of single-degree and multi-degree of
freedom systems—natural frequency, resonance, eigenvalues and eigenvectors; Application of vibration principles to balancing, design of isolators and suspension systems; Principles of active and passive vibration suppression systems using transducers and feedback.

It is envisaged that the unified approach emphasized in these courses will help the students appreciate design of systems as a holistic process and show them how this process can be improved by incorporating modern microprocessors in the loop, which is currently practiced, for example, in high-end automobiles.

Laboratory Experiments

The topics covered in the lectures will be followed by relevant laboratory exercises in order for the students to clearly understand the integration of related disciplines and their interface. About fifteen laboratory experiments are being designed and implemented as a part of this project. The objective of these experiments is to understand system behavior, effects of various parameters on its behavior and effectiveness of various techniques to control its behavior—including microprocessor control. It is planned to involve selected undergraduate and graduate students in the design and development of the experiments, testing and the manual preparation.

These experiments will provide the students with experience in system modeling, system analysis, control, data logging and data analysis, and system identification. Some examples of the material covered by the experiments are given below:

- **Position control with varying magnitude and types of loads:**

  The objectives of this experiment are to understand the effects of load and control strategies on system performance. Performance indices like overshoot and settling time will be monitored. Two types of drives will be studied. An electromechanical system and an electro-pneumatic system will be examined. The students will model and simulate the performance in MATLAB® and compare it with experimentally obtained data. Inertial loading on the machine and friction characteristics will be changed to study load effects. They will also explore the effect of compensators and additional feedback loops on system performance. This experimental setup will be configured to accommodate large variations. In doing the experiments the students will also learn about limitations of transducers, digital data logging using A/D converters and data analysis for signals with noise.

- **Structural modal analysis:**

  The objectives of this experiment are to model a multi degree of freedom system and verify the results using an experimental setup. Students will perform experimental modal analysis of a cantilevered beam, and a cantilevered plate using an impact hammer arrangement. They will use industry–standard software to conduct the test and will learn how to handle most of the hardware necessary to conduct the experiment (i.e., accelerometers, hammer, etc.). OROS® software package will be used for signal processing (time and frequency domain response) and LMS® will
be used to conduct modal analysis. Simulation software (FEM – I–DEAS) will also be utilized to compare experimental results to the ones predict by simulation. The experiment can also be configured to use an electromagnetic shaker arrangement instead of an impact hammer. This will allow the students to learn the most commonly used approaches to conduct experimental modal analysis in industry.

As mentioned previously, the experiments will be designed such that they represent a real-world situation. Some of these experiments will be multi-disciplinary. For example, the temperature control system may emulate a heat treatment bath used in a manufacturing plant, the position control system may emulate a CNC milling machine, and the speed control system may emulate a cruise control system of an automobile. The students will also be exposed to advanced control applications used in today’s cars such as ABS brake systems, traction control systems to cite examples. It is hoped that these experiments will help the students grasp the fundamentals, their integration and identify the common thread connecting all these disciplines.

All the laboratory experiments are designed to provide:

- An understanding into the nature and behavior of the system.
- An understanding of the physical principles used in the system as well as the transducers.
- An understanding of the controller employed in the system, if any.

The laboratory also houses some real world advanced control systems for demonstration purposes to kindle students curiosity as they are made available by some of our student’s corporate sponsors.

It is hoped that the students will see the connection between earlier courses like Dynamics, Physics and Mathematics-Differential equations and Systems through this integrated laboratory experience. These courses will prepare the students for more advanced elective courses in Control Systems, Fluid Power Servo Systems, Mechatronics, and Automotive Control Systems etc. The laboratory is designed to accommodate some modifications for these courses too. This project when implemented fully will add value to our Mechanical Engineering specialties such as Automotive Engineering, Machine Design and Bio-Medical Engineering.

**Impact on students**

The faculty members involved in this project are currently teaching one or more of the courses that will form these two core courses. All of them have an excellent teaching record, conviction and a strong desire to make this project a success. These two courses are required as core courses for all the 1300 Mechanical Engineering students of Kettering University. With the inclusion of hands-on laboratory experience, the effectiveness of teaching and the resulting student understanding should improve significantly. The courses are expected to be very intensive.

**Evaluation**
Evaluation is an integral part of this project. Quantitative assessment will be done by Kettering University's office of institutional research. The project team is in the process of identifying potential outside evaluators. The Assessment tools will also include student surveys. Qualitative assessment will be conducted throughout the implementation part of the project. This will allow for modifications and improvements in course content and delivery. The team will also make qualitative assessments based on the outcomes such as exam results, student design projects and number of undergraduate papers which the students may co-author.

Conclusions

In this paper the status of the implementation of two new core courses at the Mechanical Engineering Department at Kettering University is discussed. The courses aim to integrate hands-on experience into Dynamic Systems teaching. By using a unified approach (bond graph) with laboratory experience and software simulation tools, it is shown that this goal can be achieved. The courses are laid out in order to promote multi-disciplinary subject learning which allows students an easier understanding of real-world engineering problems.

REFERENCES:

4. Undergraduate Laboratories in Control Systems, NSF Award # 9551579,
5. New Approaches to Integrating Research and Education at Harvey Mudd College, NSF Award # 9873831
6. "Engineering Clinic Issues" Symposium, NSF Award # 9453953

ARNALDO MAZZEI is an Assistant Professor of Mechanical Engineering at Kettering University. He received his Ph.D. in Mechanical Engineering from the University of Michigan in 1998. He specializes in dynamics and vibrations of mechanical systems and stability of drivetrains with universal joints. His current work relates to modal analysis, stability of drivetrains, finite element analysis and CAE. He is a member of ASME, ASEE and SEM.

RAM S. CHANDRAN is an Associate Professor of Mechanical Engineering at Kettering University in Flint. He received his B.E., and M. Tech degrees from India and his Ph. D., from Monash University, Australia. He actively pursues research in the areas of fluid power servo systems, modeling, simulation and controls.

Richard Lundstrom is a Professor of Mechanical Engineering at Kettering University. He received his Ph.D. in Dynamic Systems Engineering from the Oakland University in 1984. He specializes in dynamic systems with applications in automotive chassis, powertrains and advanced machinery. His current work relates to vehicle dynamics and vehicle dynamics CAE and objective measurements. He is a member of ASME, ASEE, SAE and ASQ.
Appendix A

MECH-330 Dynamic Systems I

Catalog Data: Credit (4-0-4)

Prerequisites: Dynamics, Differential Equations including Laplace transforms, Numerical methods and Matrices, Fluid Mechanics, and Elements of Electrical Circuits.

This is a first course in System Dynamics. The objective of this course is to provide an understanding into basic principles and methods underlying the steady state and dynamic characterization of physical systems and components. The focus is on multi-discipline approach. Construction of mathematical models of systems using Bond-graph and computer simulation (both in time and frequency domains) using software tool(s) is emphasized. Application of modeling techniques to understanding the behavior of free vibration (damped and undamped), forced vibration for harmonic excitation, and systems involving multi-degree-of-freedom-including applications such as vibration absorber will be discussed.


Course Learning Objectives:

Upon completion of this course the student will be able to:

1. Model simple engineering systems involving one and at least two disciplines such as electrical, mechanical (translation and rotation) and fluid combinations. Develop the linear State Equations in Matrix form. Determine characteristics from the state equation including characteristic equation, transfer functions, time constant, natural frequency and damping ratio [ME PO: A, B, C, E and L].

2. Model simple mechanical systems (translation, rotation and a combination of both) and develop equation of motion using force and/or energy balance methods. Determine system characteristics from the equation of motion including characteristic equation, natural frequency, critical damping and damping ratio. [ME PO: A, B, C, E and L]

3. Evaluate the system performance in Time domain using Laplace and inverse Laplace transforms and Transfer functions. Evaluate the significance of characteristic equation in system performance [ME PO: A, B, E, L, P and S]

4. Simulate the system performance in time domain using accepted professional simulation tools such as MATLAB/SIMULINK [ME PO: A, C, E, K, L, M and S].

5. Design simple systems to meet certain performance objectives using the modeling and simulation techniques, using MATLAB/SIMULINK, detailed in the course [ME PO: A, B, C, E, K, L, M, O and S].
Topics covered:

<table>
<thead>
<tr>
<th>Week</th>
<th>Topics</th>
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<tbody>
<tr>
<td>1</td>
<td>Introduction to Bond graphs, bond graph elements their constitutive relationships.</td>
</tr>
<tr>
<td>2</td>
<td>Equivalent arrangement of interconnected elements, causality and development of constitutive relationship based on causality assignment.</td>
</tr>
<tr>
<td>3</td>
<td>Modeling of First order systems of different domains. Solution(s) in time domain.</td>
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<td>4</td>
<td>Modeling of second order and higher order systems and development of state space matrix models.</td>
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<tr>
<td>5</td>
<td>Modeling of mechanical systems using energy and force balance. Development of equation of motion.</td>
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<tr>
<td>6</td>
<td>Analysis and application of state space method to Single degree of freedom damped and undamped systems, including eigen values, natural frequency, damping ratio and simulation using MATLAB/SIMULINK.</td>
</tr>
<tr>
<td>7</td>
<td>Analysis and application of state space method to single degree of freedom response, transmissibility and vibration isolation. Also use of MATLAB for these applications.</td>
</tr>
<tr>
<td>8</td>
<td>Analysis and application of state space method to two degree of freedom systems. Eigen values and eigen vectors. Also use of MATLAB for these applications.</td>
</tr>
<tr>
<td>9</td>
<td>Design of vibration isolators and vibration absorbers. Simulation using MATLAB/SIMULINK.</td>
</tr>
<tr>
<td>10</td>
<td>Modeling of multi-domain systems such as electromechanical, electrohydraulic and other type of systems. Simulation and analysis of multi-domain systems in time domain using MATLAB/SIMULINK.</td>
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<tr>
<td>11</td>
<td>Comprehensive multi-domain design project including simulation and analysis of simulation run time data. Simulations using MATLAB/SIMULINK.</td>
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Schedule:

Two sessions per week of 120 minutes.

Computer usage:

Basic computer skills (MS Word, Excel) and some familiarity with MATLAB/SIMULINK.

Relationship to professional component:

This course is 75% Engineering Science and 25% Engineering Design.

Appendix B

MECH-430 Dynamic Systems II

Catalog Data: Credit (4-0-4)

Prerequisites: Dynamic Systems I
This is a second course, follow up course, in System Dynamics. The objective of this course is to provide an understanding into basic principles and methods underlying the steady state and dynamic characterization of feedback control systems. The focus is on multi-discipline approach as in the previous course. Construction of mathematical models of systems using Bond-graphs, block diagrams and development of transfer functions and state space models is emphasized. System performance is studied mainly using computer simulation (both in time and frequency domains) software tool(s). Design of control systems is attempted using the same computer simulation tools. Introduction to some advanced
topics in control systems is also provided.


Course Learning Objectives:

Upon completion of this course the student will be able to:

1. Model simple engineering systems involving multiple feedback loops. The system will include at least two disciplines, such as electrical-mechanical, electrical-fluid-mechanical combinations. [ME PO: A, B, C, E and L].

2. Analyze the system performance in Time and Frequency domains-Laplace/inverse Laplace transform solution for simple cases, evaluate the characteristics of equations for natural frequency, damping ratio, eigen value and system performance. [ ME PO: A, B, C, E, L and S].

3. Evaluate the system performance characteristics, such as stability, based on accepted matrices in time and frequency domains.[ ME PO: A, B, E, L and S].

4. Simulate the system performance in time and frequency domains using accepted professional simulation tools, such as MATLAB/SIMULINK. [ ME PO: A, C, E, K, L and S].

5. Design simple controllers, such as, P, PI, PD and PID, for systems to meet certain performance objectives using the modeling and simulation tools, such as MATLAB/SIMULINK, detailed in the course. [ ME PO: A, B, C, E, K, L, and P].

Topics covered:

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<tr>
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<tbody>
<tr>
<td>1</td>
<td>Introduction to Feedback Control systems, functional block diagram of open loop and closed loop systems, Bond graph modeling of systems</td>
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<tr>
<td>2</td>
<td>Bond graph modeling of systems, Development of Block diagrams, Development Transfer functions, and development of State space vector model of systems</td>
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<tr>
<td>3</td>
<td>Continuation of Week 2 topics</td>
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<tr>
<td>4</td>
<td>Continuation of Week 2 topics</td>
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<tr>
<td>5</td>
<td>Performance of feedback systems in time domain- first and higher order systems</td>
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<tr>
<td>6</td>
<td>Continuation of Week 5 topics and determination of performance characteristics of systems using time response.</td>
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<tr>
<td>7</td>
<td>Steady state error, Sensitivity and stability of feedback systems,</td>
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<tr>
<td>8</td>
<td>Frequency response of feedback systems.</td>
</tr>
<tr>
<td>9</td>
<td>Root locus plotting of system transfer function(s)</td>
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</table>
10 Design of controllers using root locus techniques
11 Application frequency response techniques to system design. Comprehensive Test

Schedule:

Two sessions per week of 120 minutes.

Computer usage:

Basic computer skills (MS Word, Excel) and some familiarity with MATLAB/SIMULINK.

Relationship to professional component:

This course is 75% Engineering Science and 25% Engineering design.