Development of Vibration and Control Systems Through Student Projects

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Abstract

Team projects were designed and assigned to students in a combined mechanical vibrations and controls course in the Department of Mechanical Engineering at Mississippi State University. The students were asked to work in different groups to build vibration or control systems using knowledge they learned from that class. This paper highlights four dynamic systems the students developed. Those systems will be permanently implemented into the curriculum as equipment in teaching future students. A series of lab sessions can be designed using those developed facilities to enhance teaching effectiveness and student learning experience in that class. Student feedback to a course evaluation questionnaire is also presented.

Keywords

Vibrations and controls, teaching assessment, experimentation, design project.

1. Introduction

Vibrations and controls are highly multidisciplinary subjects which encompass almost all engineering disciplines. A variety of vibrations and controls courses, including laboratories, are offered through different engineering departments in four-year colleges and universities. The Department of Mechanical Engineering at Mississippi State University (MSU) offers *Introduction to Vibrations and Controls* to all its senior students and the goals of this course are to provide students with a clear understanding of vibrations and control systems, develop their capacity to study dynamic response of structures and process systems, and enable them to design feedback control systems. This course used to be purely lecture-based and emphasized too much on solving equations and theoretical concepts. Previous student questionnaires and assessment data reflected that since this course was very conceptual, many concepts and phenomena about system dynamics, vibrations, and controls are too abstract for the students to understand. Therefore, this course had to be restructured by implementing laboratory experimentation to reinforce the concepts and knowledge learned from class lectures through hands-on experiments and help the students to better understand the vibration and control theories from the observed behavior of practical dynamic systems.

Educational laboratory equipment for demonstration of vibration and control phenomena are available but are very expensive. For example, a mass-spring-damping system with two degrees of freedom costs $18K and a complete free and forced vibration apparatus costs more than $25K. Recognizing the need of the laboratory equipment for the vibrations and controls course and concerning the high cost of commercial vibration and control apparatus, we designed a number of team projects for the students to build the educational vibration and control systems at much lower cost. Implementation of these projects into the curriculum led to a reorganization of the course materials, which were also accompanied with an effort of replacing traditional textbooks with open materials available at internet resources in engineering education. Educational approaches demonstrated by Liu et al.[1-5] were employed in this study for project implementation and syllabus renovation.

2. Description of Team Projects

Four projects were designed and assigned to the students in fall 2017 class. In those projects, students worked in teams to design and build vibration and control systems based on specified requirements applying the knowledge they learned from the class. Deliverables include an oral presentation and demonstration, a final report, and an optional peer evaluations to help the teacher to appropriately assign grade to individual team members based on their contribution and performance in the team. The semester long team project is the most important work product in the class and weighs 30% in the final grade. A brief description of these four projects are given in following sections.

<u>Project 1: Build a first-order spring-damper system</u>: Students are required to design and build a 1st order vibration system, which consists of a spring and a damping element. A team for such project should have five members.

<u>Project 2: Build a second-order spring-damper system</u>: Students are required to design and build a 2nd order vibration system, which consists of a mass, an adjustable spring, a damper, and a linear variable differential transducer (LVDT) sensor. The project team should have eight members.

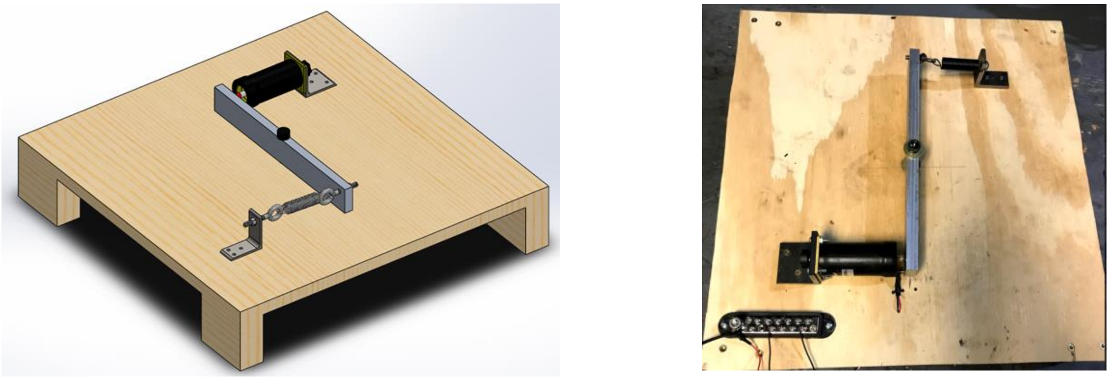
<u>Project 3: Thermocouple project</u>: Given potentiometers, resistors, op-amps, batteries, breadboard, thermocouple, and wiring, to i) construct a system and determine the relationship between temperature and output voltage; ii) determine the time constant and gain of the motor/potentiometer assembly; iii) construct a feedback control system. A team for such project should have four members.

<u>Project 4: Electrical scale project</u>: The purpose of this project is to build an electrical scale that will weight up to 40 pennies. The circuit for the scale will be constructed using an assortment of operational amplifiers (op-amps), resistors, capacitors, a potentiometer, an electric motor, and a power source. A team for such project should have four members.

3. Selected Student Projects

3.1 First order spring-damper system

Fig. 1 displays a developed first order vibration system, which consists of an aluminum arm with a spring attached to one end and a damper attached to the other. The pivoted arm, spring, and damper are installed on a plywood board. The spring constant is 4.18 lbf/in and the damper is adjustable so that the damping coefficient ranges from 0 to 40 lbf-sec/in. The spring constant and damping coefficient were such chosen that the mass of the entire system can be ignored. A data acquisition (DAQ) system was designed and installed to measure the time response of the 1st order system. The DAQ system consists of a Hall effect sensor (DRV5053RAQLPG) and a multifunction I/O device that is compatible with LabView. The sensor outputs a variable voltage based on the magnitude of magnetic flux density it senses; the I/O device allows for the voltage to be recorded by a computer. A LabView program was developed to collect the data. A sampling frequency of 200 Hz was used so the voltage would be measured every 5 ms. Total cost for building such a system is $266. With the implementation of the developed first order system, lab sections can be designed to measure its time constant, estimate its damping ratio, and predict its time and frequency response.



(a) (b)

Figure 1. Developed 1st order vibration system: (a) CAD model; (b) prototype

3.2 Second order mass-spring-damper system

The developed second order vibration system is shown in Fig. 2. This system reflects a vertical design and its core component is a mass-spring-damper system. One uniqueness of this design is that the mass, spring, and damper are either interchangeable or adjustable. By manipulating the viscosity of the fluid in the oil container, the surface area of the disk inside of it, and the spring constant, underdamped and overdamped responses can be observed from the second order system. Lab sessions will be developed based on this seconder order vibration system for students to determine its natural and damping frequencies, measure its transient and steady state responses, study the over-, critically, and underdamped cases. Total cost for building this system is about $1,200. A steel frame was machined to hold the mass-spring-damping system and a carriage was designed to transport the mass up and down along the frame. An LVDT (Schaevitz HR 2000 LVDT) was attached to the system to detect the displacement of the mass and translate that into electrical signal. The generated electrical signal was then translated into readable data through a signal conditioner. As explained in Fig. 6, the inserting rod of the LVDT was attached to the mass carriage system and the cylinder of the LVDT was attached to the bottom of the steel frame. A signal generator was connected to the LVDT and grounded to the signal conditioner, a National Instruments myDAQ device, to create a differential input signal for LabView to display the waveform and append the received data to a text file.

Figure 2. Prototype of 2nd order vibration system

3.3 Thermocouple project

Fig. 3 shows a thermocouple designed by a student team, which is able to convert temperature into a voltage which could then power a motor. In this design, a feedback control system was created using potentiometers, resistors, operational amplifiers, batteries, a breadboard, circuit wiring, and a Type-K thermocouple, with a total cost about $75. Its circuit consists of several inverting op-amps, voltage followers, a high-voltage-high-current (HVHC) op-amp, K-type thermocouple wire, several rotary potentiometers, a motor, and two 6V batteries connected in series to power the op-amps and the rotary potentiometer. In this system, the potentiometer acts as a controller for the feedback control loop and the motor is the output. Thus, the measured temperature is converted to voltage signal and the difference in voltage is then converted to output rotation speed of the motor (radians/sec). A complete feedback control system was created by combining the circuit with thermocouple wiring and the motor-potentiometer assembly.

Figure 3. Thermocouple design

3.4 Electrical scale project

An electrical scale designed by one student team is presented at last, which can weigh up to 40 pennies and display the weight of the pennies (Fig. 4). In this design, a bar strain gage load cell was used to weigh the pennies. In the load cell, strain gages are attached on each end of the bar to measure the tension applied on the bar as well as compression resulting from bending distortion. The strain gates convert the measured strain to a change in resistance. The change in resistance is then amplified through an HX711 load cell amplifier, which works as a Wheatstone bridge circuit to generate an amplified voltage signal. Finally, the voltage signal is converted into weight through an Arduino and displayed on a LCD screen. The Arduino platform consists of a microcontroller circuit board and an integrated development environment (IDE) software. The microcontroller is attached to the circuit while IDE runs a code to control the circuit and the display on the LCD screen. The circuit board is connected to a computer that is running the IDE software. The Arduino circuit board and the LCD screen are wired onto a breadboard. Total cost for building such a system is about $55.

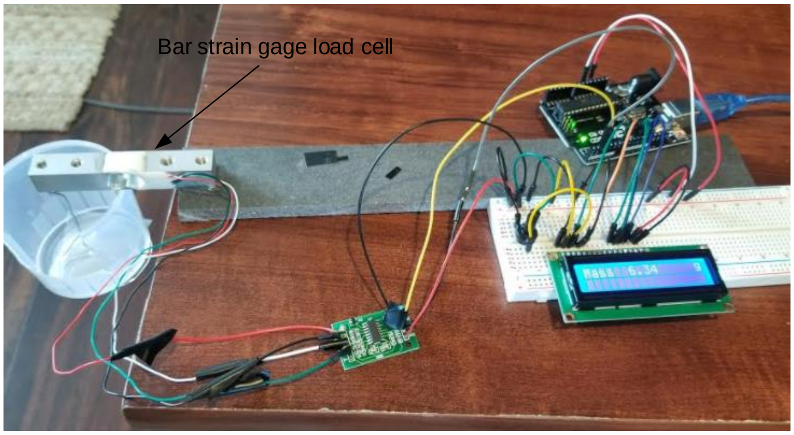


Figure 4. Electrical scale using a bar strain gage load cell

4. Student Evaluation

Table 1 shows how students compared their level of knowledge for related topics before and after this course. In that table, “1” represents the lowest ranking and “5” represents the highest ranking for each skill and topic. The numbers in the cell represent the number of student who chose that particular point. For instance, the number “20” in the row of “Laplace transform” means that 20 students selected “3” for that question. Mean scores were calculated based on the students’ feedback for each of the 6 closed-format questions in terms of “before the class” and “after the class”. The column “Δ” lists the differences between the “After Course” mean values and the “Before Course” mean values. For example, in the row of “Laplace transform”, the mean value before the class is 2.95 and after class is 3.71, which means that the average “organization skill” point of the entire class had been 2.95 while it reached 3.71 after the class. Its “Δ” = 3.71 – 2.95 = 0.76 shows that that skill was increased by 0.76 points through this class. As shown from that column, the “Δ” values range from 0.76 to 1.55 with a perfect score of 5, which proves that this course significantly enhanced students’ skills and knowledge.

Table 1. Assessment and results on course goals

	Before Course December 2017					**Mean**	**After Course** December 2017					**Mean**	**Δ**
Topics	1	2	3	4	5		1	2	3	4	5		
Laplace Transforms		13	20	7	2	**2.95**		1	15	21	5	**3.71**	**0.76**
Vibrations	11	21	9	1		**2.00**	1	3	18	12	8	**3.55**	**1.55**
Fourier Analysis	18	11	11	1	1	**1.95**	5	8	19	6	4	**2.90**	**0.95**

Linearization	15	9	15	3		**2.14**	5	8	9	15	5	**3.16**	**1.02**
System Modeling	13	16	8	5		**2.12**	2	4	10	22	4	**3.52**	**1.40**
Feedback Controls	26	8	6	2		**1.62**	3	4	21	12	2	**3.14**	**1.52**

5. Conclusions

In this study, the *Introduction of Vibrations and Controls* was substantially restructured from a purely lecture and textbook-dependent course to an integrated lecture-lab course with the combined use of textbook and open learning materials. Projects were assigned in the beginning of the semester and students worked in teams to design and build vibration and control systems using theories and knowledges learned from the lectures. The implementation of those team projects provided students excellent training to work in a group and interact with others to elucidate complicated vibration and control behavior of dynamic systems thereby greatly advanced their understanding on this subject. The develop vibration and control systems will be permanently integrated into the curriculum, based which a series of lab sessions can be designed to enable future students to reinforce their understanding on vibration and control theories and principles through hands-on demonstration and experimentation. Course assessment results showed that most goals of this course were achieved and overall the students were very satisfied with the renovated course and recognized the effectiveness of the projects in growing their knowledge bases and developing their problem solving capacity, hands-on experience, and teamwork skills.

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