

Implementation of MATLAB/Simulink into A Vibration and Control Course for Mechanical Engineering Students

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Abstract

This paper presents a curriculum development effort of implementing MATLAB and Simulink into a vibrations and controls course for mechanical engineering (ME) students at Mississippi State University (MSU). MATLAB/Simulink is the most widely used programming tool used by vibration analysts and control designers. In the past, the MSU students did not have enough training to use this software tool to facilitate the design and analysis of dynamic systems such as vibration and control systems. Building upon an experimental lab section established in a previous curriculum enhancement project, the author has introduced MATLAB/Simulink into his class "Introduction to Vibrations and Controls" and devised computer lab sessions in parallel with the existing experimental lab sessions to establish a complete lab section for that class. The students now may not only observe and characterize the dynamic response of vibration and control systems through experimental operations and measurements, but also validate experimental results and confirm experimental phenomena through computational analysis, as well as exploring dynamic behaviors of the systems in a variety of conditions through numerical simulations with different settings. Student feedback reflects that the integration of MATLAB/Simulink into the curriculum provides an effective way to develop the ME students' programming skills and strengthen their capacity in modeling, simulating, and analyzing vibration, control, and other dynamic systems. The developed computational lab and the current experimental lab complementarily promote student understanding of principles and concepts conveyed in classroom lectures.

Keywords: Vibrations and Controls, MATLAB/Simulink, Mechanical Engineering, Computational Lab, Programming

Introduction

MATLAB is the most widely used program in vibrations and controls courses and by practitioners in this field. It is consistently listed in the 10 most in-demand technical skills that employers are looking for¹. Simulink, which is based on MATLAB and uses a diagram-based interface, is increasing in popularity because of its power and ease of use. Historically, mechanical engineering (ME) students at Mississippi State University (MSU) have not received enough MATLAB and Simulink training, which limit their chances of being employed by the most recognizable companies in the world. In order to overcome this barrier to further improve the competitiveness of the ME students by improving their programming skills, the author has launched an effort to integrate MATLAB and Simulink into his "Introduction to Vibrations and Controls" course at MSU.

Since 2017, the author has helped his students to design and build more than 10 vibration and control apparatus, which have been integrated into his class to form an experimental lab section^{1,2}. Several vibration and control systems designed and built by previous student teams are

exhibited in Figure 1.

In addition to experimentation, the use of software programs is essential in obtaining numerical results for the students to understand and describe physical behaviors of the developed dynamic systems. As a powerful programming tool, MATLAB not only possesses strong capabilities for engineering calculation and graphing but also allows the students to develop their skills in coding and user interface design³. This paper presents details in the project of integrating MATLAB and Simulink into the vibrations and controls class and developing a computational lab section based on the new curriculum.



Figure 1. Vibration and control systems developed by previous student teams

Method

MATLAB/Simulink is incorporated into the vibrations and controls course through three ways: homework assignments, team projects (experimentation and software), and individual projects (software only).

Homework Assignments: The textbook being used for that course, *System Dynamics*⁴ has stand-alone sections in most chapters providing extensive coverage of MATLAB and Simulink relevant to its chapters' topics. Students will self-learn the MATLAB and Simulink through reading illustrations of that software and practicing examples and complete homework assignments. Homework problems include using MATLAB to solve mass-spring-damper systems, frequency response problems, application problems, and using Simulink to model and analyze control systems.

Team Projects: The team projects previously designed for the course^{1,2,5,6} will be upgraded by incorporating a computational part. In the updated projects, in addition to designing, building, and demonstrating dynamic systems, the students also need to use MATLAB and/or Simulink to model their systems and plot the systems' dynamic response, and assess their designs by interpreting the computational results and comparing them with the measured experimental data.

Individual Projects: Several individual projects were designed and assigned to students for them to complete independently. Compared with the team projects, the individual projects offer more flexibility for students to work at their own pace and develop their independent thinking and independent problem-solving skills. Also, the individual projects allow the instructor to assess

individual students' learning and performance while overcoming the challenge of fairly evaluating students' work based on their individual contributions in a team project.

Examples of the team projects designed for this vibrations and controls class have been illustrated in the author's previous work^{1,2}. An example of the individual project is presented below.

Fig. 2 illustrates a vehicle system, which includes a vehicle body (as denoted by subscript "C"), two suspensions (as denoted by subscript "B"), and four wheels (as denoted by subscript "W"). The equation of motion of this system is (damping effect is neglected)

$$[M_V] \ddot{X} + [K_V] X = 0 \quad (1)$$

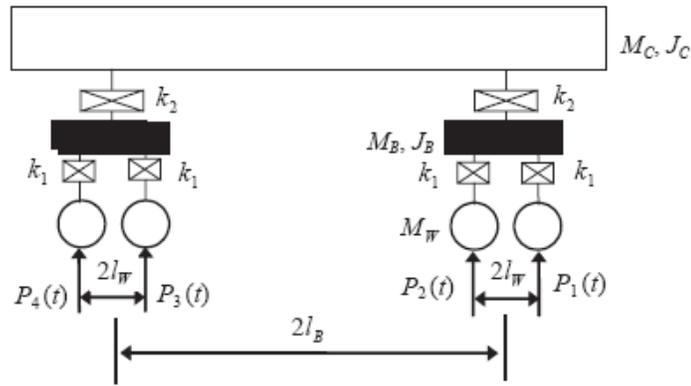


Figure 2. A simplified vehicle-suspension-wheel model

In Eqn. (1), X is the displacement vector of the vehicle system; M_V is the mass matrix, and K_V is the stiffness matrix. M_V is defined as:

$$[M_V] = \text{diag}(M_C, J_C, M_B, J_B, M_B, J_B, M_W, M_W, M_W, M_W) \quad (2)$$

and K_V is defined as:

$$[K_V] = \begin{bmatrix} 2k_2 & 0 & -k_2 & 0 & -k_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2k_2 l_B^2 & -k_2 l_B & 0 & k_2 l_B & 0 & 0 & 0 & 0 & 0 \\ -k_2 & -k_2 l_B & k_2 + 2k_1 & 0 & 0 & 0 & -k_1 & -k_1 & 0 & 0 \\ 0 & 0 & 0 & 2k_1 l_W^2 & 0 & 0 & -k_1 l_W & k_1 l_W & 0 & 0 \\ -k_2 & k_2 l_B & 0 & 0 & k_2 + 2k_1 & 0 & 0 & 0 & -k_1 & -k_1 \\ 0 & 0 & 0 & 0 & 0 & 2k_1 l_W^2 & 0 & 0 & -k_1 l_W & k_1 l_W \\ 0 & 0 & -k_1 & -k_1 l_W & 0 & 0 & k_1 & 0 & 0 & 0 \\ 0 & 0 & -k_1 & k_1 l_W & 0 & 0 & 0 & k_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -k_1 & -k_1 l_W & 0 & 0 & k_1 & 0 \\ 0 & 0 & 0 & 0 & -k_1 & k_1 l_W & 0 & 0 & 0 & k_1 \end{bmatrix} \quad (3)$$

In this project, students are required to (1) assign proper values with a consistent system of units for all the parameters and build matrices [M_V] and [K_V]; (2) use MATLAB to find and display natural frequencies of this system; (3) use MATLAB to find normalized mode shapes associated with their respective frequencies; and (4) use Simulink to create a model for this system and

visualize the mode shapes through animation. A project final report needs to be submitted by the end of the semester.

Fig. 3 displays a Simulink model created by a student for a speed control system using an armature-controlled DC motor. Fig. 4 shows the motor current and the output speed for a step-command input, which were plotted through running a MATLAB simulation.

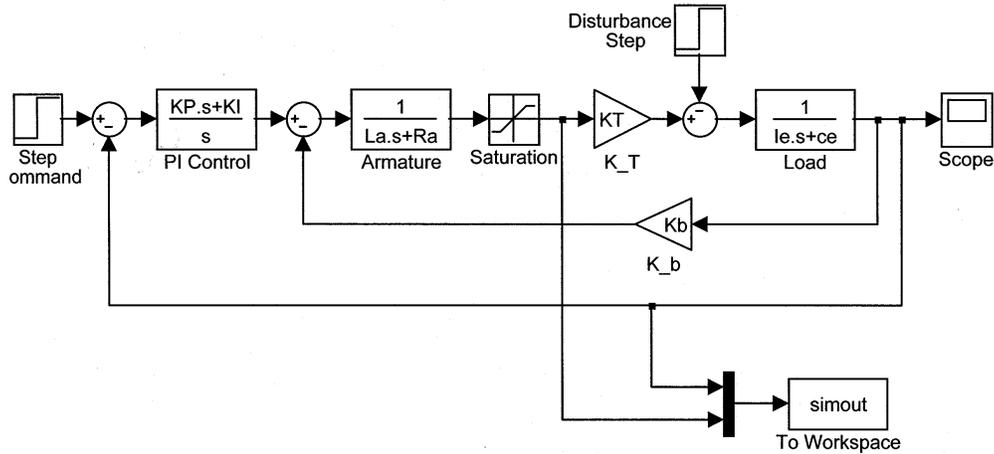


Figure 3. A Simulink model for a speed control system

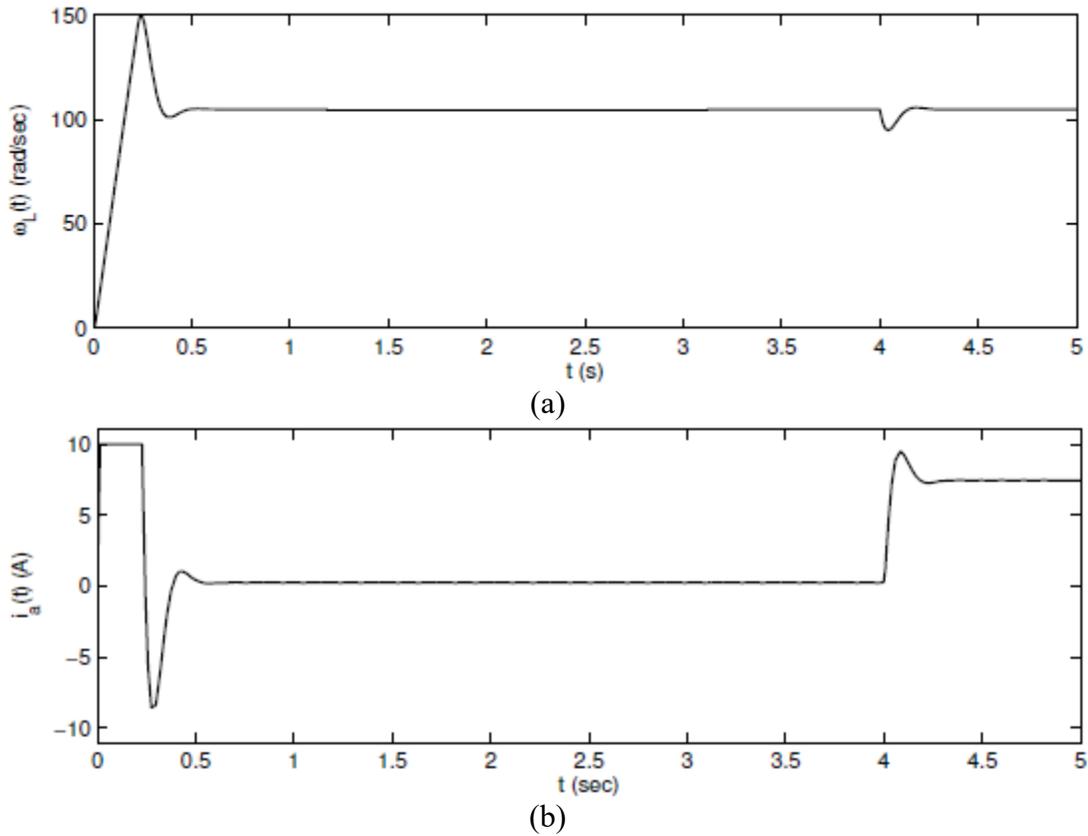


Figure 4. Motor current (a) and output speed (b) of the control system in Fig. 3

Results and Assessment

A course evaluation was conducted at the beginning of November for the Fall 2019 class to collect feedback from the students for future adjustment and optimization of the course curriculum. A course assessment questionnaire was created based on a published evaluation model⁷ to evaluate the effectiveness of the implemented computational lab in developing students’ MATLAB and Simulink skills, deepening their understanding of the vibration and control phenomena observed from the experimental lab, and strengthening their self-learning capacity. This questionnaire was handed out to students in classroom and the students were given one week to complete and turn this survey back. All the students who took this course in the Fall 2019 have participated in this evaluation.

Table 1 shows how students compared their level of knowledge for related topics and mastery of skills 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 students who chose that option. For instance, the number “11” in the row of “Vibrations” means that 11 students selected “1” for that question. Mean scores were calculated based on the students’ feedback for each of the 5 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 “Vibrations”, the mean value before the class is 2.05 and after class is 3.64, which means that the average “Programming skills” point of the entire class was 2.05 while it reached 3.64 after the class. Its “Δ” = 3.64 – 2.05 = 1.59 shows that that skill was increased by 1.59 points through this class. As shown from that column, the “Δ” values range from 0.62 to 1.65, which proves that the integration of the MATLAB and Simulink section considerably enhances their capacities in using MATLAB/Simulink to model, solve, and analyze vibration and control problems, and in self-learning. The developed computational lab also promotes student understanding of principles and applications of this course.

Table 1. Evaluation questions and student feedbacks

Topics/Skills	Before Course					Mean	After Course					Mean	Δ
	1	2	3	4	5		1	2	3	4	5		
Vibrations	11	15	11	1		2.05		1	14	22	2	3.64	1.59
Feedback controls	22	13	3	1		1.56	1	8	13	16	1	3.21	1.65
Programming skills	9	17	9	5	1	2.32	3	5	18	10	4	3.18	0.86
Self-learning capacity	4	18	12	5	1	2.53		3	13	15	7	3.68	1.16
System modeling		2	13	20	4	3.67			4	20	15	4.28	0.62

Table 2 compares the average increases (Δ) of the listed topics and skills for the class with and without the MATLAB/Simulink section. From the values it can be seen that the effectiveness of this revised course in improving student understanding on vibrations is a little bit higher to the previous curriculum. However, the addition of the computational lab does not influence the instruction of principles and methods of vibrations, and measurably improves the programming and self-learning of the students, as well as their understanding on feedback controls.

Table 2. Average increase (Δ) on knowledge and skills with/without MATLAB/Simulink section

Topics	Without MATLAB/Simulink	With MATLAB/Simulink
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Vibrations	1.55 ²	1.59
Feedback controls	1.52 ²	1.65
Programming skills	N/A	0.86
Self-learning capacity	0.65 ²	1.16
System modeling	1.40 ²	0.62

Conclusions

MATLAB and Simulink were introduced into a vibrations and controls course taught in the ME Department at MSU. A computational lab was designed based on the newly added MATLAB/Simulink section. The computational lab complements the existing experimental lab to form a complete lab session for this course and provide students with a full lab experience. Effectiveness of the present course revision was evaluated through a survey study. The survey results showed that the integration of MATLAB and Simulink into the vibrations and controls class helps the students to develop their MATLAB and Simulink skills and gain a better understanding of principles and concepts of vibrations and controls. The outcomes of this project and the previously developed vibration and control apparatus jointly forms a complete lab section for this class that includes both computational and experimental components. Implementation of this project also encourages the students to self-study MATLAB and Simulink from relevant sections of the textbook or other resources and helps them to sharpen their self-directed learning ability, which satisfies the ABET requirement for engaging engineering students in life-long learning.

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