Special Issue of National Conference NCIEME 2016 Organised by Rajarambapu Institute of Technology and Walchand College, Sangli ISSN 2394 - 1707

Teaching Linear Control Systems: a Core Course in Electrical and Electronics Engineering

JaveedKittur

Electrical & Electronics Engineering,
B.V.Bhoomaraddi College of Engineering &
Technology, Hubballi – 31, Karnataka
javeed@bvb.edu

Abstract: This paper presents the experience in teaching the course Linear Control Systems in Electrical and Electronics Engineering curriculum. This course is offered to third year engineering students. Students who pursue a degree in Electrical and Electronics Engineering are required to complete a laboratory course in the same semester. The motivation for offering this course is to make the students aware regarding the importance of control systems, controller design aspects and verification of designed systems through simulation. In order to have a system function as per the requirement, the understanding of control systems engineering is very essential. This paper presents the experience of teaching linear control systems course of an instructor for the first time with the incorporation of peer learning; Think – Pair – Share activity and personal mentoring of students. The students' performance scores of different tests are presented. Students' feedback is also included which clearly shows that the instructor has put efforts in doing justice in teaching this course.

Keywords: Linear control systems, pedagogy, teaching experience, student mentoring

1. Introduction

Control engineering plays a very important role in all the control system applications ranging from a simple washing machine at household to F – 16 fighter aircraft of high performance [1]. Interconnection of different components which configures a system to obtain a required system response is a control system. The systems under control are getting complex day by day and obtaining their optimum performance is a major concern, hence control systems engineering is gaining a wide importance [2].Control engineering aims at understanding the physical systems through mathematical modeling in the form of inputs and outputs of a system.

Javeed Kittur
Department of Electrical & Electronics Engineering,
B.V.Bhoomaraddi College of Engineering &
Technology, Hubballi - 31
javeed@bvb.edu

A system may be electrical, mechanical, biological, chemical, etc. Depending on the type of the design problem, the mathematical modeling, analysis and controller design uses the frequency, time and complex – s domains of control theory. The use of system analysis, modeling and systems with feedback control and its applications are majorly seen in automobile industry, vibration and sound control, industrial machinery, and many other areas of engineering [3]. This drastic and rapid growth has resulted in increasing need for students of engineering to have a thorough expertise in controller design, modeling, simulation and analysis of a feedback control system [4].

At B. V. Bhoomaraddi College of Engineering and Technology, Hubli, India, Linear Control Systems (LCS) is taught as a core course of 4 credits to students of Electrical & Electronics Engineering department at fifth semester. In the same semester a control system laboratory is also included which runs hand – in – hand with the theory course. The following are the learning outcomes of the course;

At the end of this assignment the students will be able to,

- Describe the role of controllers, explain with examples the open / closed loop control systems, develop the transfer function models of electrical and mechanical systems by writing a set of differential/algebraic equations for each of component/subsystem and represent by block diagram.
- Demonstrate an understanding to simplify the model represented by block diagram of a complex system by (i) applying reduction rules and (ii) obtaining signal flow graph of the system and applying Mason's gain formula.
- Explain the significance of time response methods and specifications, design controller to meet the specified time response specifications, analyze the system performance of a given control system and

carryout simulations using software.

- Demonstrate an understanding of the absolute/relative stability of linear control systems, apply Routh-Hurwitz criterion to evaluate and analyze the stability as a function of specified system parameters.
- Explain the significance of frequency response methods, its specifications and correlation with time response specifications; reshape the frequency response in the form of polar and Bode plots and employ the same to design controller/compensator to meet specified frequency response specifications and analyze the system performance, and carryout simulations using software.
- Demonstrate an understanding of the importance of root locus techniques in the design and analysis of linear control systems, apply various rules to obtain the root locus of a given control system, analyze its performance and carry out simulations using a software.
- Analyze the performance of various controllers such as on-off, proportional, integral, derivative, PI, PD and PID for a given control system, design controller/compensator to meet the given time/frequency response specifications and carry out simulations using a software.
- Simulate the designed systems using Scilab simulation tool.

The work presented in this paper shares the experience of an instructor teaching the course 'Linear Control Systems' for the first time. The first section of the paper gives a brief introduction as to why students should learn control systems and why analysis, design and simulation are important. The second section discusses the methodology adapted in teaching the course which will aid students' learning. The third section talks about the implementation and results of this methodology. Discussions are taken up in the fourth section of the paper. The subsequent sections include conclusions and references.

2. Methodology

The course Linear Control Systems is core course of 4 credits. This course is allotted with 50 teaching hours and the breakup of this is shown below in table 1 and the Continuous Internal Evaluation (CIE) Scheme is shown in table 2.

Table 1. Course split up in terms of chapters and hours allocation

Unit	Chapter		Hours
1	1	Introduction to Control Systems	3
	2	Transfer function models and block diagram representations	8
	3	Block diagram simplification	6
	4	Time response analysis of first order system	3
2	5	Time response specifications	6
	6	Stability analysis of control systems	6
	7	Frequency response analysis	8
3	8	Root locus diagrams	6
	9	Basic principles of feedback control	4

Table 2. CIE Scheme

Assessment	Weightage in Marks
Minor Examination – 1	20
Minor Examination – 2	20
Assignments	10
Total	50

The class which underwent this course had strength of 80 students. As per the college norms minor examination – 1 and 2 are subjective examinations and are conducted as per the schedule given in advance (calendar of events) which accounts for a total of 40 marks out of 50 marks of CIE. The remaining 10 marks are allotted for assignments. The Semester End Exam is for 100 marks which will be scaled to 50 marks, thereby making the total (CIE + SEE) as 100. The syllabus of minor 1 includes the entire unit 1 which has 20 hours of portion and syllabus for minor 2 includes the complete unit 2 which is also of 20 hours. Unit 3 is of 10 hours, all these 3 units is the portion for the semester end examination. The assignment included design of controller parameters (manual calculations), programming (coding), analysis, simulation and documentation. The assignment submissions were done using an app called 'Edmodo', which is an online platform majorly used to discuss, share and learn from peers.

In chapter 1, the students have been exposed to the necessity of control, control objective, control law and different practical open loop and closed loop control systems. Chapter 2 focuses on linear and non – linear systems, time variant and time invariant systems, deriving transfer functions for electrical and mechanical systems and representation of the same by block schematic. Chapter 3 discusses the block diagram reduction rules required to obtain the transfer function for a given block diagram, signal flow graph and Mason's gain formula to determine the transfer function. Chapter 4 introduces the concept of poles, zeros, order and type of a system, standard test signals, unit step response of a first order system and time response specifications.

In unit 2, chapter 5 deals with the determination of error constants and steady state errors, time response specifications of a second order system and design of P, PI and PID controllers using Ziegler – Nichols tuning method. Chapter 6 focuses on necessary and sufficient conditions for system stability, Routh – Hurwitz criterion, special cases of difficulty and methods to overcome stability problems. Chapter 7 introduces the frequency response analysis, approximate polar plot and bode plots, determination of phase and gain margins from polar and Bode plots.

Chapter 8 briefs on concepts of root locus, magnitude and angle criterion, rules to construct root locus diagram and example on the same. Chapter 9 deals with the basic modes of control and their features.

3. Implementation and Results

Portions of the course have been taught by chalk and talk method, peer learning, active learning and collaborative learning activities. Even though chalk and talk approach was used, the teaching primarily focused on giving personal attention to students and motivating them. After teaching a concept to the students, they were asked to apply their

learning in solving a given problem. The instructor approached the students individually in the class and helped them to complete the solution for the given problem. Also, students who obtained the solution early were asked to help their classmates. At different stages Think – pair – share activity was used to promote thinking among students and learning from others. Based on the students approach towards a problem and performance scores in the test, the students were mentored personally by the instructor.

The performance score of minor examination – 1 and minor examination – 2 are shown below in Fig 1 and Fig 2. The performance scores of minor exam – 1 are pretty good as 52 students have scored more than or equal to 85% marks, 18 students have scored in the range 60 – 80% and 10 students have scored very less. The performance scores of minor exam – 2 are also good as 25 students have scored more than or equal to 80%, 28 students have scored in the range 60 – 80% and 27 students performance is low. However, in comparison the performance scores of minor exam – 1 are higher than minor exam – 2.

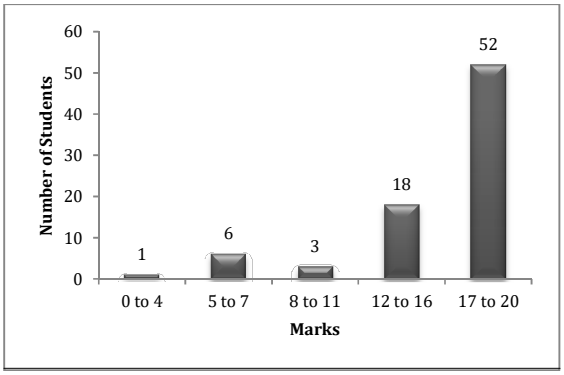

Fig 1. Performance Scores of Minor 1

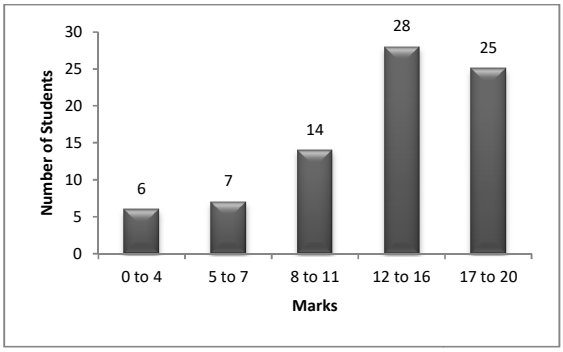

Fig 2. Performance Scores of Minor 2

The average score of minor exam – 1 is 16.28, the standard deviation is 3.96 and the coefficient of variation is 0.24. The average score of minor exam – 2 is 13.52, the standard deviation is 4.57 and the coefficient of variation is 0.34. The maximum score of minor exam – 1 and 2 is 40 marks. The assignment for this course is for 10 marks which included controller design and verification of the same by simulation. The attainment of different parameters of the assignment is shown in Fig.3. The attainment of all the parameters is good, 'Simulation' being the highest and 'Documentation' being the lowest. A laboratory course was an add-on to this course which focused on practical implementation of few concepts learnt in theory.

The performance scores of semester end exam for the year 2015 and 2016 are shown in Fig. 4. From Fig 4, it is clear that the semester end exam grades of the year 2016 are greater than 2015. However, the course offered in the year 2015 was by another instructor. As a fresher in delivering this course in the year 2016, the instructor might have been liberal in giving marks in certain aspects. Also, the approach used in teaching the course by the two instructors is very much different. There is a drastic increase in 'S' grades obtained in the year 2016. Also there is 88.88% increase in 'A' grades in 2016 and 85.72% increase in 'B' grades in 2016. The numbers for failures for both the years however remained the same.

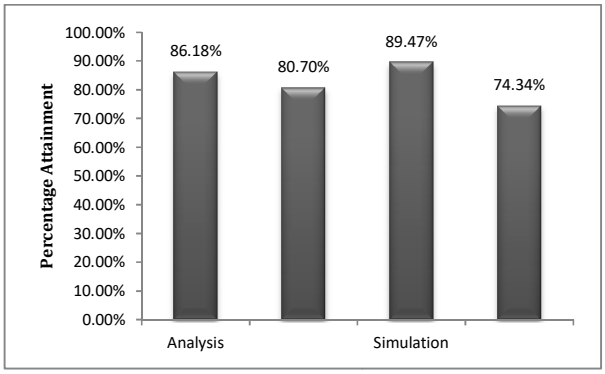

Fig. 3 Attainment of various parameters (Analysis, Design, Simulation and Documentation)

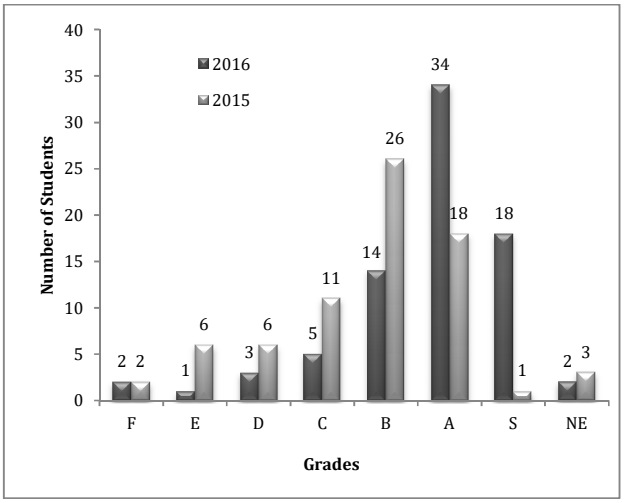

Fig 4. Semester End Exam Grades for 2015 and 2016

4. Discussion

The strategy used in delivering the course linear control systems to closely monitor the students learning and performance, included course instructors rigorous observation of students' behavior in the class and their involvement, peer learning and think – pair – share activity.

The assessment plan was strategically designed and prepared to measure the attainment of the learning outcomes by the student. The performance scores of minor exam – 1 are better than minor exam – 2 because students were provided with the instructor written notes and good amount of revision of the topics was done for the syllabus of minor exam – 1.

At the end of the course each student gave a feedback which essentially included ten questions addressing about the ease/difficulty in learning while undergoing this course, comfort level in using the simulation tool, designing controller parameters and others. A total of 65 students gave the feedback out of 80 students. As per the feedback most of the students concluded that influence of faculty written notes provided to students has a positive impact on their scores. Very few students prefer reading from the text books as reading from faculty written notes is easy because all the related explanation is available in a single document.

The following section discusses the student feedback. In the next cycle of delivery of this course the instructor would like to collect the feedback also through focused group discussion, also self and peer assessment to be included in assignment and laboratory sections.

A. Students Feedback

- Do you like to read text books or faculty written notes for the subject Linear Control Systems while preparing for exams? 63.08% of the class said faculty written notes and 36.92% of them said text books.
- The performance score in minor 1 was very good because; 24.62% of the class said the syllabus for minor 1 was taught well, 13.85% said question paper was easy, 32.32% said faculty gave the written notes which helped my preparation and 29.23% said Similar questions to that asked in minor 1 were discussed in class.
- The overall performance score in minor 2 of the class is less as compared to the minor 1 performance score. This is because; 18.46% of the class said the syllabus for minor 2 was not taught well, 32.31% said question paper was very difficult, 27.69% said faculty did not give the written notes and hence I could not prepare well for the exam and 21.54% said similar questions to that asked in minor 2 were not discussed in class.
- To what extent do you feel the faculty has done justice in teaching the course Linear Control System? 51.56% of the class said 80 – 100%, 29.69% said 60 – 80%, 9.38% said 40 – 60%, 7.81% said 20 – 40% and 1.56% said 0 – 20%.
- Are you happy with the evaluation of minor exam 1 and 2? 93.85% of the class said 'Yes' and 6.15% of them said 'No'.
- Rate your learning in the course Linear Control Systems; 34.38% of the class said 80 – 100%, 42.19% said 60 – 80%, 18.75% said 40 – 60%, 3.13% said 20 – 40% and 1.56% said 0 – 20%.
- How confident are you in applying the concepts and skills learnt in Linear Control Systems course to any other subjects? 18.46% of the class said 80 – 100%, 43.08% said 60 – 80%, 21.54% said 40 – 60%, 13.85% said 20 – 40% and 3.08% said 0 – 20%.
- On an average how much time of the class did you use effectively? 33.85% of the class said 80 – 100%, 44.62% said 60 – 80%, 15.38% said 40 – 60%, 4.62% said 20 – 40% and 1.54% said 0 – 20%.
- How confident are you of doing well in semester end exams? 42.19% of the class said 80 – 100%, 46.88% said 60 – 80%, 4.69% said 40 – 60%, 4.69% said 20 – 40% and 1.56% said 0 – 20%.
- Did you enjoy attending the classes of Linear Control Systems course? 96.61% of the class said 'Yes' and 3.39% said 'No'.
- Rate your practical skills in the course Linear Control Systems; 22.95% said 80 – 100%, 37.70% said 60 – 80%, 29.51% said 40 – 60% and 9.84% said 20 – 40%.

5. Conclusions

This paper presents the experience of an instructor of teaching the course linear control systems for the first time using conventional and non – conventional approach of teaching. From the students' performance scores and the feedback it can be concluded that the students' learning and the outcomes have been achieved. The assignment in the course has also incorporated the controller design skills and simulation skills in students. The semester end exam grades of the students in the year 2016 are good in comparison with the grades of students in the year 2015.

Acknowledgement

The author would like to thank the principal, B.V.Bhoomaraddi College of Engineering and Technology, Hubballi. The author would also like to thank HOD and Dr. S. R. Karnik of Electrical & Electronics Engineering department for their continuous support and guidance.

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Special Issue of National Conference NCIEME 2016 Organised by Rajarambapu Institute of Technology and Walchand College, Sangli ISSN 2394 - 1707

June 23 – 26, 2013.