A Unique Approach to Teaching Dynamic Systems and Control

Colonel Wayne E. Whiteman, Ph.D., P.E.
Associate Professor and Mechanical Engineering Program Director
Department of Civil and Mechanical Engineering
United States Military Academy
West Point, NY 10996

Abstract

The Departments of Civil & Mechanical Engineering and Electrical Engineering & Computer Science at the United States Military Academy (USMA) offer a course in dynamic systems and control that is well known to engineering majors in both departments due to its uniqueness and applicability. Cadets enroll in the course and are jointly taught by a faculty that is composed of both military and civilian professors from both departments. The classroom and laboratory experiences that have been designed over the past few years provide students with a broad exposure to dynamic systems and classical control theory while focusing on relevant applications. This paper presents an overview of the dynamic systems and control experience created at USMA and offers several examples of its uniqueness.

Introduction

The Departments of Civil & Mechanical Engineering and Electrical Engineering & Computer Science at the United States Military Academy (USMA) offer ABET-accredited degrees in mechanical engineering and electrical engineering respectively. Students who want to major in these programs must successfully complete a course of study very similar to that required by their peers at civilian schools. Each year, approximately 65 cadets select mechanical engineering as a major and approximately 30 cadets select electrical engineering as a major. Dynamic Systems and Control is a required course to complete the mechanical engineering major, and is an elective course for the electrical engineering major.

Course Structure

The course structure includes both lecture and laboratory components. There are 35 lectures, each 55 minutes in length. The topics during the first block of the course include mathematical modeling in the Laplace domain, modeling of both mechanical and electrical systems, modeling in state-space, and linearization techniques. Time response of first- and second-order systems, block diagram algebra, stability, and steady-state error are covered during the second block. Next, root locus techniques and design using these root locus techniques are taught. Bode plots, Nyquist diagrams, gain and phase margin, and design using these frequency response techniques are taught during the fourth block. The last block of instruction is an introduction to design using state-space techniques.

Five laboratories augment the lectures and are completely integrated into the course to supplement classroom instruction. The laboratories focus on implementation of gain control and proportional derivative control, system identification using frequency response, and state-space control through pole placement techniques.

The three credit hour course also includes two 55-minute tests. The final cumulative examination completes the cadet's course requirements.

Dynamic Systems and Control Students

As mentioned in the introduction, Dynamic Systems and Control is a required course to complete the mechanical engineering major, and is an elective course for the electrical engineering major. Dynamic Systems and Control is not offered as two separate courses for these majors. Instead, students take the same course, jointly offered and jointly administered by both departments.

The total annual enrollment in Dynamic Systems and Control is typically around 100 cadets. To enhance student learning and small group interaction, the Academy restricts class size to about 16 cadets on average and a maximum of 18 cadets. This results in the creation of two to four sections per semester. Enrollment is controlled to ensure an equal distribution of mechanical and electrical students across sections. By controlling the mix of students, the interdisciplinary nature of the course is enhanced during group exercises, laboratory and design projects.

Dynamic Systems and Control Faculty

The faculty team that teaches Dynamic Systems and Control reflects the diversity of the USMA faculty. It is typically a blend of senior military faculty, civilian faculty, and junior military faculty. Special talents are brought to the teaching team by each of these groups.

The senior military faculty make up approximately 15% of the total faculty and usually have four to fifteen years of teaching experience. They are responsible for filling most of the administrative and leadership positions at the Academy.

Approximately 20 to 25% of the overall faculty at the USMA are civilian positions. These faculty members increase the disciplinary depth and expertise in particular fields. These individuals serve similar roles as their colleagues at civilian institutions and provide an important perspective different from that of the predominantly military faculty.

The majority of the faculty at West Point (the remaining 60 to 65%) are junior military officers. They are a select group of individuals that are identified to attend graduate schooling at top notch universities across the nation for two years in pursuit of a masters degree. This schooling is followed by a three year period of service on the USMA faculty.[1]

What makes the Dynamic Systems and Control faculty even more unique is that it is composed of faculty from both the Departments of Civil & Mechanical Engineering and Electrical Engineering & Computer Science. The course is jointly taught. Some semesters, sections are distributed between faculty from both departments. Other semesters, the course has been team taught with the mechanical and electrical engineering faculty sharing responsibility for individual lessons.

Course Background

Providing a practical and relevant engineering science and design background in dynamic systems and control is the overall goal of the course. Numerous examples are provided to relate the course material to military applications. The course also provides important material for use in many of the capstone design projects that cadets will experience during their senior year. The course is designed to provide a solid foundation in dynamic system modeling and classical control system theory. Table 1 is a complete summary of topic coverage.

Table 1. Summary of Topic Coverage

Subject	**Lessons-Labs**
Introduction to dynamic systems and control concepts and nomenclature	1-0
Mathematical modeling in the Laplace Domain	1-0
Modeling of electrical, mechanical, and electromechanical systems	4-1
State-space representation and linearization techniques	3-0
Time response of first- and second-order systems	2-1
Block diagram algebra	1-0
Stability	1-0
Steady-state error	1-0
Root Locus techniques	3-0
Design via Root Locus	4-1
Bode plots, Nyquist diagrams, Gain Margin and Phase Margin	4-0
Design via Frequency Response techniques	4-1
Design via State-Space techniques	3-1
Special topics	1-0
Exams	2-0

The course is supported by an internal web site. The course syllabus, requirements, and administrative information are provided on this site, along with a link to *Standards for Technical Reports*[2] to complete laboratory and written technical submissions.

The student's course grade is assigned through the use of two 55-minute exams, eight homework sets, seven computer exercises, five laboratories, a three and a half hour final examination, and an instructor grade. The graded events with associated weights are listed in Table 2.

Table 2. Graded Event Summary

Graded Event	**Quantity**	**Points**
Homework sets and computer exercises	15	250
55-minute examinations	2	150 ea.
Laboratories	5	30 ea.
Term-end examination	1	200
Instructor grade	1	100
TOTAL		1000

Course Assessment

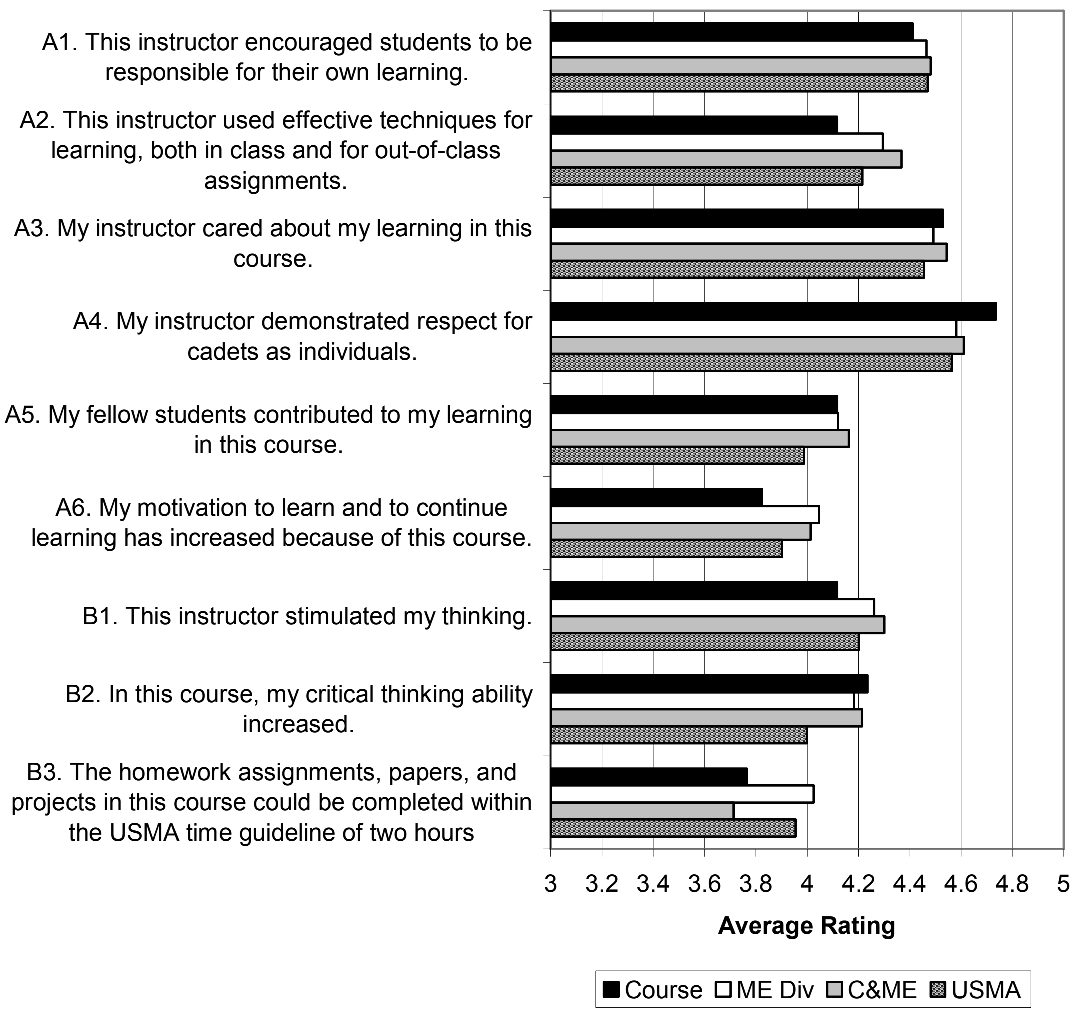
Annually, a course assessment process is conducted (See Floersheim, Bailey, and Ressler[3]). A review of the entire course is conducted using feedback from instructors and students, along with other course assessment tools. The course is structured around the following four course objectives:

- Model the dynamics of various physical systems that include mechanical and electrical components.
- Analyze a physical system that utilizes a control system and determine its ability to meet performance specifications for stability, steady-state error, and transient response.
- Design a controller for a physical system to meet a set of performance specifications using Root Locus, Frequency Response, and State-Space methods.
- Connect and integrate topics from previous mechanical engineering and electrical engineering courses.

During the course assessment process, individual lesson objectives are reviewed and modified to ensure that these course objectives are being met. At the end of each semester, cadets are asked to assess their ability to accomplish each of the course objectives. The course assessment process is also used to ensure that the dynamic systems and control course is supporting the Program Outcomes for both the mechanical engineering and the electrical engineering ABET-approved programs.

Table 3 shows recent quantitative assessment results of student development and how well teaching goals are being met. In the bar chart, the black bar represents course results. The white bar is the results for all mechanical engineering courses. Results for the Department of Civil and Mechanical Engineering and the entire United States Military Academy are depicted in the gray and slashed bars respectively. The scale is: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, and 5-Strongly Agree. These assessment results indicate that the course is well accepted and this type of format should be considered for adoption by other interested faculty.

Table 3. Course Feedback and Assessment



Each semester, a course director is assigned to the course. Responsibility for course directorship rotates between the Departments of Civil & Mechanical Engineering and Electrical Engineering & Computer Science each term. Periodic lesson conferences are conducted throughout the semester to coordinate instruction. These lesson conferences also serve as a forum to exchange ideas between faculty from both departments and enhance the student learning environment.

Lesson conferences are also a means for maintaining equity among sections. In addition, all sections are given exams of comparable content and difficulty, the same graded homework and computer exercises, and the same laboratories. Common examinations allow instructors to assess how well his or her students are progressing and to gain feedback from their fellow faculty member covering the same material. This real-time assessment process allows for needed course adjustments throughout the semester.[4]

Classroom Experience

Unique training aids allow instructors to demonstrate principles and show the relevance of control systems to the students. As an example, during the study of electromechanical systems, a dc-motor/generator is brought into the classroom as a demonstration to make the material more comprehensible to the cadets.

The University of Massachusetts, Amherst developed a computer-controlled model car (CIMCAR) to conduct simulations and experiments for automatic control.[5] In AY 1909-2000, a capstone design team of cadets built a replica of the CIMCAR for use in the Dynamic Modeling and Controls course. A picture is shown in Figure 1.

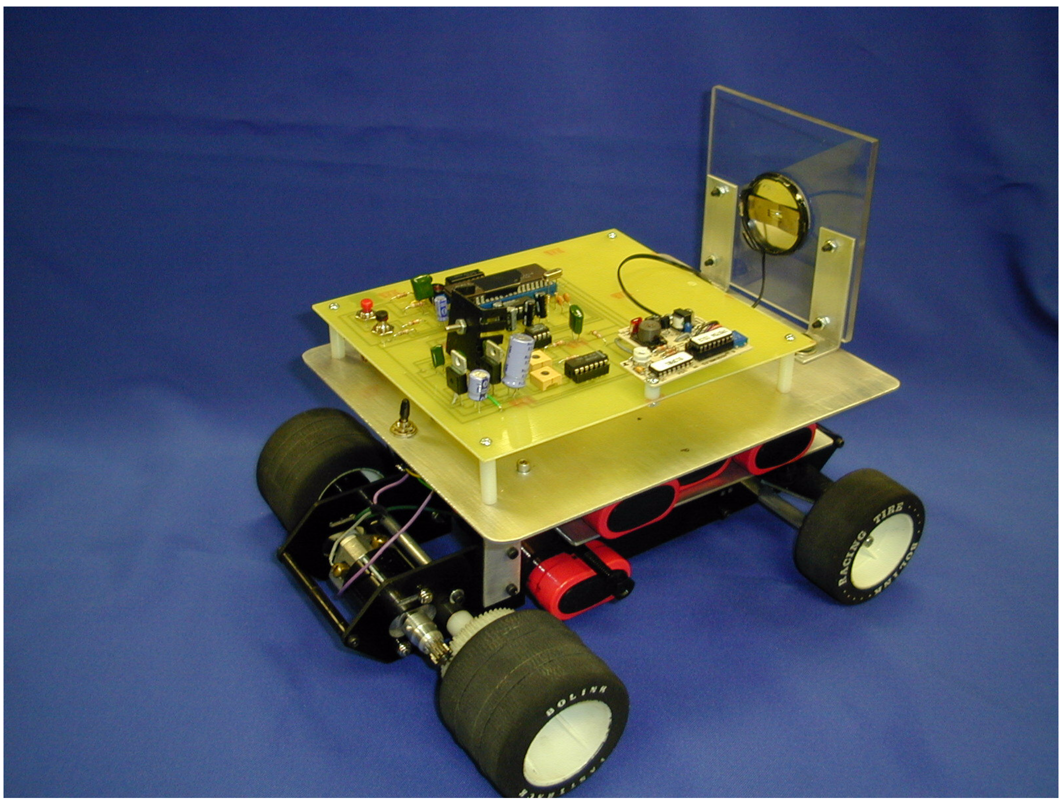


Figure 1 – Computer-controlled model car (CIMCAR)

The CIMCAR is used throughout the Dynamic Modeling and Controls course to demonstrate important concepts. It uses a controller to implement a collision avoidance task. Early in the course, the CIMCAR is a real-world example of mechanical, electrical, and electromechanical elements that must be modeled. During the time response block of instruction, the CIMCAR helps students visualize overdamped, critically damped, and underdamped responses. It also helps them in understanding the need for meeting time specifications such as peak time, rise time, and overshoot requirements. The CIMCAR is useful for demonstrating stability and steady-state error concepts for those respective lessons. Finally, the CIMCAR is used to demonstrate the use of simple proportional or gain control.

Laboratory Experience

Five laboratories are conducted as part of the Dynamic Systems and Control course. The purpose of the first laboratory exercise is to familiarize the students with a Feedback Analog Servo mechanism and to begin determining the basic block diagram parameters that characterize a system. This lab provides a good foundation for all future labs.

The second laboratory familiarizes students with positional feedback control. In addition, student teams design, build, and test a second-order position control system to a given set of time domain specifications.

The effects of a using a PD (proportional plus derivative) controller on the servo-motor trainer are investigated in the third laboratory. In the second lab, students had designed a position control system using proportional (gain only) control. Controlling the system by using only gain adjustments limited their ability to improve the speed of the transient response at the expense of increasing the amount of overshoot.

In this lab they experiment with the method of improving the transient response by adding a single zero to the system in the form of a PD compensator. The PD controller places a zero at a desired location to improve the transient response. The overall goal of the laboratory is to improve the response of the second order position control system with the PD compensator to meet specific transient response specifications for a step input.

Students perform system identification of a Twin Rotor Multiple-Input-Multiple-Output system in the fourth lab. The students develop and compare two second-order linear models representing this system. The student develops the first model using frequency response methods where the system is excited with several sinusoid inputs varying in frequency. The model's magnitude is obtained by measuring the ratio of the output sinusoid in the steady-state at each frequency to the respective input sinusoid. The model's phase is the measured difference in phase between the input and output signals. The students also develop a second model of the vertical axis of the TRMS using the time response method where data from a step input is collected and used to determine time response characteristics (such as overshoot). In both methods, the system's natural undamped frequency (ω_n) and the damping ratio (ζ) are used to categorize the second order model.

In the final laboratory, the student designs feedback gains for a full-state feedback controller to control the Twin Rotor Multiple-Input-Multiple-Output system. The student's design is based on a given state-space model and time domain performance specifications. The students must test and refine their design in the lab, recognizing the limitations of linear models and the actual equipment.

Summary

The Department of Civil and Mechanical Engineering at the United States Military Academy (USMA) at West Point, New York offers a unique approach to teaching dynamic systems and control. This uniqueness can be attributed to a variety of factors including the Academy setting, faculty and student composition, new faculty workshops, laboratory facilities, and classroom experiences. This paper presents an overview of the dynamic systems and control experience created at the USMA and offers several examples of its uniqueness.

References

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WAYNE E. WHITEMAN
Colonel Wayne E. Whiteman is an Associate Professor in the Department of Civil and Mechanical Engineering at United States Military Academy, West Point. He received his BS from the United States Military Academy in 1979, an MSCE and Civil Engineer degree from MIT in 1987, and a Ph.D. in Mechanical Engineering from Georgia Tech in 1996. Colonel Whiteman has had numerous assignments with in the U.S. Army during his more than 22 years of active duty service. He is a registered professional engineer in the Commonwealth of Virginia.