Session 1359

Incorporating Design, Communications, Teamwork, and Modeling in a Controls Laboratory Experience

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Abstract

It is now widely recognized that engineering education must include training in communication and teamwork skills in addition to traditional engineering science and design topics. This paper presents a control laboratory experience designed to provide such training in a realistic manner. This experience centers on the standard control problem of designing of a closed loop speed control system for a dc motor.

This laboratory project differs from the standard presentation in several ways. First, the problem statement is intentionally very vague. The students are simply told to design a system that accepts a target speed from a user and brings the motor to that speed. Similarly, the components supplied to the students (motors, shafts, amplifiers, bearings) do not come with specifications. To solve this problem, the students must clarify the vague user specified requirements, model the physical system mathematically, design experiments to determine the values of system parameters such as motor torque constant and bearing friction, design a control algorithm to meet the problem requirements, and build the control system.

To incorporate communication training into this exercise, the modeling and characterization tasks are divided among the student teams in the class. Each team must develop and perform experiments to determine the values of certain characteristics and present the results of their experiments to their classmates. Since all students depend on the accuracy of each groups results, useful questions are raised during these presentations. In fact, the student critiques of other students' presentations provide excellent discussions of key aspects of modeling and experimental design.

This laboratory experience has been extremely successful in achieving the objectives described above. Based on student performance and course evaluations it also had the effect of integrating a number of modeling and controls concepts in the students' minds. Included in the presentations are feedback from students and plans for future modifications to the laboratory experience.

1. Background

The University of St. Thomas mechanical engineering program seeks to combine the advantages of a liberal arts school with a rigorous introduction to engineering. As part of this, we try to show students interconnections between fields and encourage the development of "soft skills" such as communication and teamwork which are much prized by employers. Among other tools for accomplishing these goals, we believe that laboratory exercises provide ideal opportunities for students to practice teamwork and communication skills. To accomplish this, we are in the process of developing a set of laboratory exercises and design projects in a variety of topics in support of this goal. This paper documents the process we are using by which laboratory exercises can be developed based on stated program objectives and desired student outcomes.

2. Motivation

Laboratory exercises serve several purposes in the education of the engineer. In addition to reinforcing key concepts covered in the curriculum, they provide critical experience with instrumentation that must be mastered. Ideally, they also help the student develop skill in formulating their own questions, designing and performing their own experiments to answer those questions, and analyzing the results of those experiments[1]. However, it is difficult to design undergraduate laboratory exercises that accomplish all of these goals. An exercise that is sufficiently structured to demonstrate and reinforce a key concept is rarely sufficiently open-ended to provide the student with real experience in experimental design. But with the increasing need to provide engineering students with experience in teamwork and technical communication, the demands on laboratory exercises have increased. We believe that in light of this expanding view of role of engineering education, the starting point for the design of laboratory exercises must lie with the objectives and desired outcomes of the engineering program rather than the objectives of a particular course.

In addition to traditional engineering science topics, engineering programs now seek to develop another set of skills in the student. The Society of Manufacturing Engineers identified in 1997 that the primary gap between student preparation and industry expectation was in the area of "soft-skills" such as communication and teamwork[2]. The ABET 2000 accreditation criteria for any engineering program include the requirement that graduates are able to effectively communicate in writing and in oral presentations and that they are able to work effectively in teams[3]. Our own program at the University of St. Thomas has an additional requirement that students must demonstrate the intellectual curiosity, creativity and critical thinking required for innovative engineering performance. These so called "soft skills" are difficult to incorporate into an engineering curriculum as they are behaviors learned through practice rather than knowledge learned through more traditional pedagogical approaches. We believe that laboratory exercises offer an excellent opportunity for students to practice these behaviors and to obtain feedback on their performance in a non-threatening manner.

In addition to the laboratory objectives mentioned above, we see the opportunity to use laboratory exercises to accomplish another goal as well. Our department has set as an objective that our students understand the interconnections between the seemingly disparate subjects they study in college. This objective includes not only their engineering topics such as thermodynamics, mechanics, and control theory, but also what they have learned in their core curriculum classes such as writing and presentation skills, ethics, and, history.

With these goals in mind, we set out to modify a traditional laboratory exercise in dynamic system control to serve new purposes. In the past, we have used the classic closed loop control of a dc servo motor to provide students with hands-on experience in PID control and control system tuning as is commonly done in courses in dynamic system modeling and control. This is a system that is described in nearly every introductory text and used in many introductory courses[4,5]. This exercise provides valuable learning opportunities, and reinforces key modeling and control concepts but does not address any of our additional objectives. In particular, we wished to modify this exercise to incorporate the following:

- Teamwork beyond a typical laboratory exercise, preferably including brainstorming, team directed division of labor, and individual initiative in support of team goals.
- Communication skills, including not only written and oral presentations, but critical listening and reading skills.
- Experimental design skills, not necessarily in the sense of statistical design of experiments but in terms of developing experiments to determine missing data required for task completion.
- Use of previously learned skills, to reinforce the interconnections between subjects. In particular, we were seeking to reinforce topics from mechanics, electronics, system dynamics, and control theory.

Experimental design practice could be built into the motor control exercise by requiring students to determine model parameters through experimentation. However, this does not accomplish the remaining objectives. Rather than individual system modeling projects, we decided to present the class with a single project in which they would attempt to develop a control system for a poorly understood system, requiring the students to identify important characteristics, divide the modeling tasks among themselves, devise and perform appropriate experiments, present the results to one another, and use their results to generate a control system.

3. Exercise Description

This laboratory exercise is offered as part of our junior level course on dynamic system modeling, simulation and control (ENGR 410). Prerequisites for this course include introductory courses in analog and digital electronics (ENGR 350), computer programming (QMCS 230), and introductory engineering design (ENGR 151) as well as calculus, linear algebra and differential equations. The laboratory exercise is conducted late in the semester, and several key topics have been covered in the course before this exercise is attempted. These include the modeling of dynamic systems in time and frequency domains and specifically the modeling of dc motors. Students in the course have received some exposure to the use of Matlab and Simulink as tools for system modeling and control system design but have had little practice using these software packages before this exercise. They have studied different specifications of system performance such as settling time, percent overshoot, and steady state error. Each laboratory station is equipped with a PC containing an A/D - D/A board, power supplies, a signal generator and an HP oscilloscope, and 2 fluke DMMs as shown in figure 1. In prior laboratory exercises, students have written software to read analog inputs, process them, and produce analog outputs using the PC. They have also encountered aliasing of undersampled signals, and written software to perform numerical differentiation and integration.

Figure 1. Controls Laboratory Bench Configuration

Armed with this array of tools, knowledge and skills, the students are presented with the mechanical system shown in figure 2. This system consists (from left to right) of a small dc motor, flexible coupler, bearing, main shaft, 2 aluminum cylinders of differing length and diameter, a second bearing, another flexible coupler, and a tachometer (in the form of a second dc motor). The students are also given a power Op-Amp mounted in an appropriate heat sink to convert the low power analog signals from the PC to signals that can power the motor as shown in figure 3. The Op-Amps are mounted and wired in such a way as to allow the students to follow the electrical connections in the feedback loop and model the op amp behavior using the

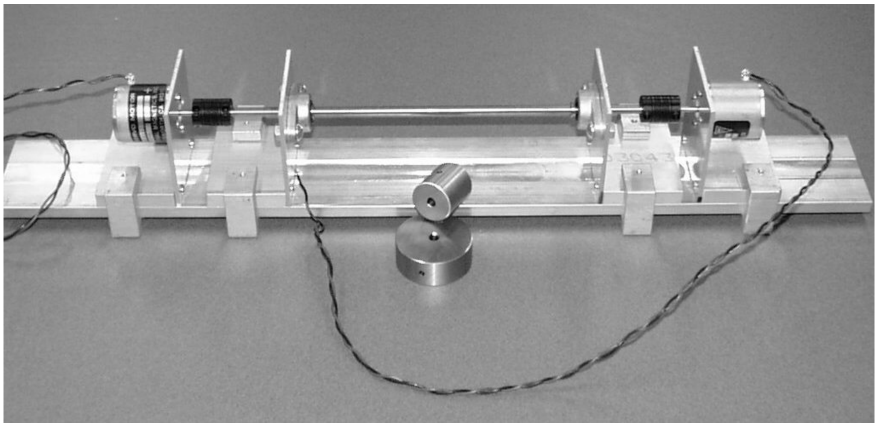

Figure 2. Motor - Tachometer Apparatus

circuit theory learned in their electronics class as well as noting the power supply bypass capacitors and observing various techniques for making electrical connections.

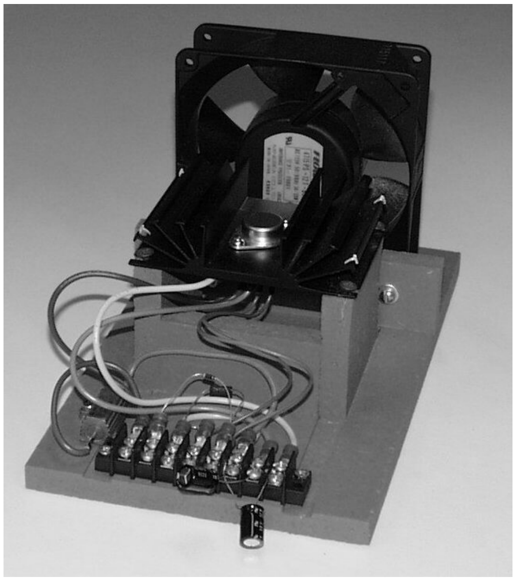

Figure 3. Power Op-Amp

The lab assignment is a single sentence: "Write a control program that brings the shaft to a user-specified speed as quickly as possible." Students are given a due date, told that cooperation is encouraged and left to their own devices, with the laboratory instructor serving the role of facilitator and answering any questions that arise.

The students quickly realize that there are a number of tasks that must be performed before they can even consider writing a program. At this point most students describe the required tasks as:

1. Identify important system parameters
2. Determine the values of those parameters
3. Model the system and control loop
4. Optimize control loop parameters in simulation
5. Write the control software

The students then attempt to identify the key system parameters. This is a good point for the laboratory instructor to introduce idea generation concepts such as brainstorming and tools such as Ishikawa diagrams for ensuring completeness. The students then generate block diagram models for the system. They can be encouraged to use Simulink as a drafting tool at this point since they know they will be using it later to simulate their control system. A typical student generated model is shown in figure 4, and has the following parameters:

1. Amplifier gain
2. Motor Resistance
3. Motor Moment of Inertia
4. Motor Torque constant
5. Motor Back-Emf constant
6. friction coefficient
7. Viscous damping coefficient
8. Shaft inertia
9. Load inertia
10. Tachometer back-emf constant

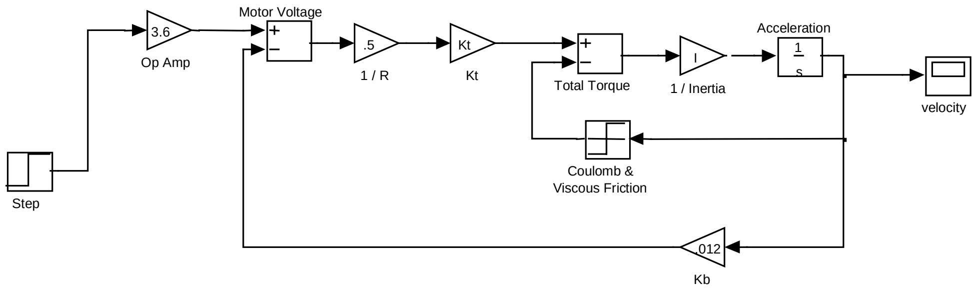

Figure 4. Student Model of Motor System

Some students consider including the inductance of the motor and others object leading to useful discussions and learning experiences. Recognizing the large number of parameters that need to be estimated and the short time available, the students than divide the parameters among themselves. If the students are slow to recognize the need for subdividing the problem or disorderly in the allocation of tasks, the laboratory instructor can again step in at this point to provide instruction on these skills.

Generally, the students' first attempts at devising experiments for these parameters are flawed because they are unable to find individual experiments that determine single parameters. Instead most experiments they devise reveal values of ratios of parameters or other, even more complex interrelationships. Eventually, after discussion between groups, they arrive at a set of experiments that collectively determine the values of all parameters. A typical approach is to use a stroboscope and ammeter to measure motor speed and current draw at varying input voltages to determine motor resistance and back-emf constant. Motor inertia can then be determined by adding different known load inertias in the form of aluminum cylinders and measuring fractional change in inertia. Torque constant can be determined by measuring response time to changes in input current. Friction coefficient can be determined by finding the torque required for constant speed. Amplifier gain can easily be determined by measuring input and output voltages (and compared with the theoretical value obtained from circuit theory). There are other ways of determining these parameters and it is quite exciting to see what the students come up with.

In the course of performing these experiments, the students usually discover important parameters they had overlooked or discover interactions between characteristics that they had not expected. Also, they discover that the tachometer output does have a dc value proportional to motor speed, but also has an ac component corresponding to brush noise. They usually decide to reduce this with an RC filter, which requires them to practice their design skills from the electronics class.

Since each lab group has determined only two or three of the required parameters, they must share their results with one another. In our lab, each group presents their proposed experimental method early in the process and their experimental results later. Since each group is dependent on valid results form the other groups, everyone is highly motivated to cooperate and point out potential flaws in experimental methods and technique. The early presentations are generally quite poor, but well critiqued by other students, while the presentations of final methods and results are smoother.

Finally, when they have a model and begin to simulate the effects of a control loop, the students generally realize that they are not sure what is meant by the phrase “as quickly as possible”. At this point, we generally encourage a diversity of solutions by giving each lab group a different set of performance criteria in terms of allowable % ripple or overshoot. Each group then uses Simulink to model their control system as shown in figure 5 and optimize their control parameters.

4. Results

In terms of the issues that motivated the development of this lab, there are several notable results:

- students are very interested in presentations and ask good questions
- students have developed creative ways to determine parameters
- students have learned how to use new tools (stroboscope, Simulink)
- students have learned to recognize and solve problems

When students exposed to this laboratory exercise move on to their senior design clinic, we have observed that they are better able to work in teams, are more creative, and

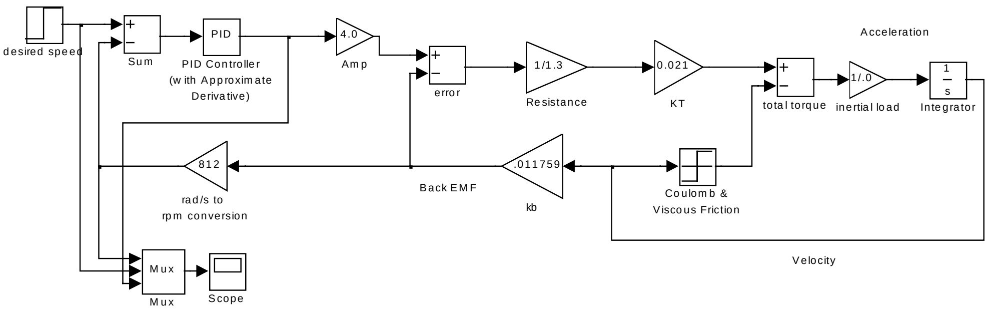

Figure 5. Student Model of Control Loop

communicate ideas and concerns more clearly than prior seniors who had been exposed to more traditional control system exercises.

We have also observed that students enjoy this exercise. The student evaluation ratings for this course were among the highest in the department and student comments on the course evaluation included the following:

- “With all the real-life design incorporated in the class, it made it way more fun.”
- “I really enjoyed the lab portions in that we designed everything.”
- “Most practically beneficial class I’ve ever had. I probably learned more and made more connections in this class than any other.”
- “Great! I loved the open-ended experiments in the lab. You learn so much more this way. This is also a great source of design in the engineering degree.”

5. Conclusion

Based on student performance in the controls class and subsequent performance in the senior design clinic, it appears that the laboratory exercise introduced has helped the students develop the ability to design and conduct experiments as well as follow and critique the work of others. It is harder to evaluate the success of the exercise at improving teamwork skills. However, an indication of these skills is the success of this year’s senior design project which was a large team project for a local medical device firm. The students who had performed this team lab exercise worked far more cooperatively than earlier project teams and needed less coaching on these skills. Overall, the exercise appears to have met its objectives.

6. Acknowledgements

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Jeff Jalkio received his PhD in Electrical Engineering from the University of Minnesota and worked for several years in industry in the fields of optical sensor design and process control. In 1984, he co-founded CyberOptics Corporation with Steve Case, where he headed research and development. In 1997 he returned to academia, joining the engineering faculty of the University of St. Thomas where he teaches courses in electronics, mechatronics, controls, and design.