CTL Fellows Report
ENGR 312 — Automatic Control Systems: Hands-on Exercises
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1 Introduction to Control Theory

Systems and controls are fundamental to the engineering discipline; most if not all physical engineering processes are dynamic with behavior changing through time. In order to make machines or processes behave as desired, engineers must create mathematical models of physical systems to intelligently prescribe a series of inputs to control the system state. Take, for example, controlling an automobile speed via modulating the throttle angle, or the temperature in a multistory building via various HVAC components. Clearly controls is broadly applicable across engineering, and is a key component of a well-rounded engineering education.

Unfortunately, oftentimes systems and controls courses are difficult for engineering undergraduates. The content is abstract and requires mathematical rigor, and physical intuition is oftentimes lost on students. While prerequisite courses may be in-place to encourage preparation for the course, student struggle to unify concepts from various courses in application to controls. Consequently, many controls courses include a mathematics refresher portion and lack any hands-on component.

1.1 Controls at Trinity College

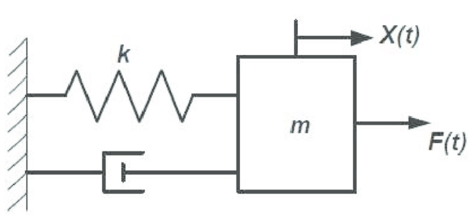
For Trinity engineers of all concentrations, ENGR 312 - Automatic Control Systems is a required course. Prerequisites include:

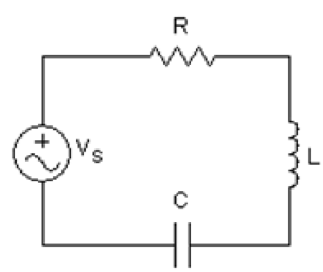
- MATH 231 - Caculus III
- ENGR 212L - Linear Circuit Theory

The latter has prerequisites that ensure students have also taken:

- MATH 234 - Differential Equations
- PHYS 231L - Electricity & Magnetism and Waves

These prerequisites ensure that students are familiar with some of the basic tools required, and importantly have analyzed the equations that govern the behavior of basic electrical and mechanical systems, such as those shown below.





The course is historically lecture-only, and typically taken by 3rd and 4th year students. Students are expected to abstract mathematical models, and implement theoretical techniques to control real physical systems. Because of the high-level of abstraction, the disconnect between theory and physical application can be frustrating for students. While students are required to have encountered several of the theoretical tools needed to succeed in the course, they may not have used these tools in several years.

1.2 Goals

ENGR 312 was offered in the Fall Semester of 2018. For this course, I was interested in introducing hands-on and group activities in order to:

1. better meet students at their level of understanding
2. encourage group learning opportunities among students
3. reinforce course content through application

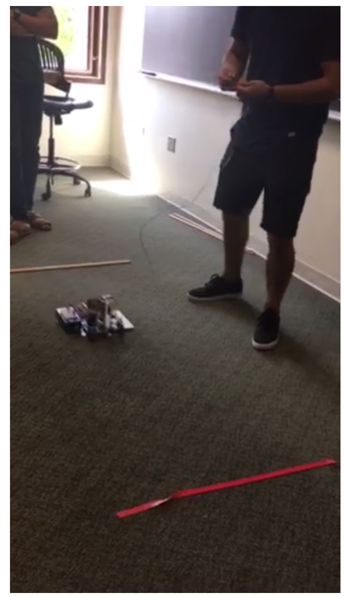
2 Implementation

2.1 Catering to Student Level of Understanding

Since students enter ENGR 312 with different backgrounds (both in terms of mathematical handle and engineering concentration), I administered a concepts quiz on the first day of class. Quiz concepts included:

- basics of calculus (e.g. explain what integrals and derivatives are)
- solving linear ordinary differential equations
- solving systems of linear equations
- first and second order systems

The quiz was graded completely on completion and served as a check-up, or worst case a wake-up call, for students. As the instructor, I found this tool useful in that it informed me the relative level of preparedness of each student. In addition to this concepts quiz, the students were formed into groups and worked on a motivational group-exercise with low barrier to entry. Groups were tasked with manually controlling the position of a one-degree-of-freedom robotic cart, as shown here.



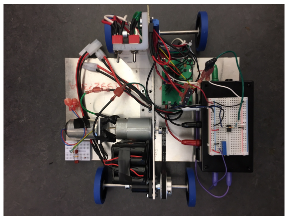
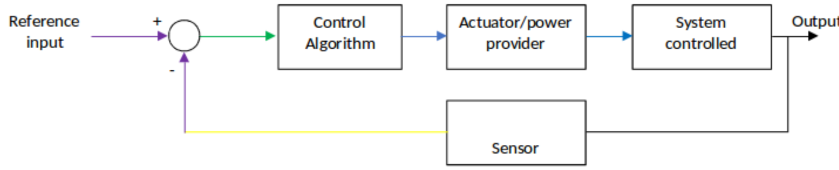
The robotic cart used in this course, named the Fidget Car, was developed as part of a workshop at Dartmouth College led by Dr. Laura Ray and funded by the National Science Foundation under Grant No. DUE-1611672 and the IEEE Control System Society Outreach Fund.

2.2 Group Learning Opportunities

In addition to the group exercise from the first day of class, students were also afforded the chance to work together on in-class worksheets. After each new section of material, sample problems which simulated very closely that week's or subsequent week's homework were administered and to be completed in assigned groups of 4-5 students. These opportunities were designed with the aim of giving students the chance to check-in on their own progress, teach one-another, seek clarification in a low-pressure setting, build confidence and learn from each other. Because the problems matched very closely with homework problems, the hope was also that students would have less trouble on completing individual assignments.

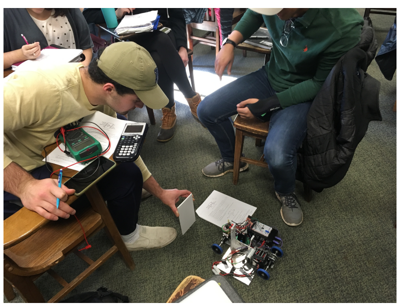
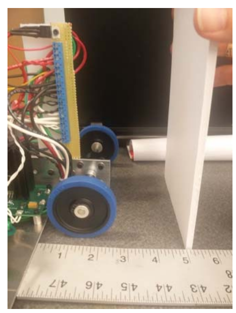
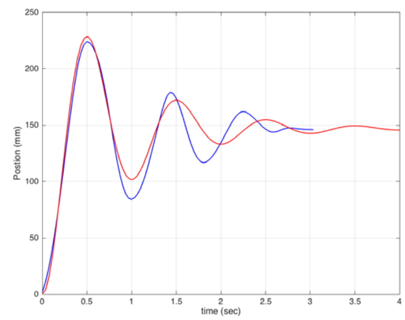
2.3 Hands-On Application

While an official laboratory section was not implemented in ENGR 312, hands-on lab exercises were assigned in the lecture period. The goal of these exercises was to extend and solidify abstract course concepts. For example, the first step in building control systems is to abstract a mathematical model of the physical process. This is requisite to leverage underlying control theoretic principles to affect intelligent behavior of any system. In groups, students were asked to de-construct the physical components of Fidget Car into corresponding mathematical ones.

The assigned task was for students to dissect the physical system on the left to a mathematical representation, shown as a block-diagram, on the right. System equations and specific values are added to the final block-diagram.

In their final hands-on exercise, students were tasked with implementing a proportional-integral controller on the Fidget Car. This controller, would in effect, perform the same task the students were asked to complete manually on the first day of class except in an intelligent and automatic fashion. Students would ideally recall the drawbacks of the manual controlled exercise, and appreciate the efficacy of the control concepts accrued throughout the course. This exercise is depicted below.

3 Observations

In the course of executing this project, I made several observations of note:

- while exciting, the first-day hands-on exercise may have been misleading to students; subsequent lecture periods were neither as exciting nor as easy to grasp
- group sizes of 3-5 may have been too large, less motivated group members seemed to be less engaged - a system of paired students may facilitate better participation
- formal hands-on laboratories would benefit the course, and was expressed explicitly by students

4 Future Outlook

In future opportunities to teach this material, I would like to incorporate more simple intuition building exercises, e.g. masses on springs. Additionally, I would move from groups of 3-5 to pairs in terms of in-class worksheets, and incorporate a game-element to hopefully boost student participation. Finally, incorporation of a series of progressively complex physical systems may be helpful.

Acknowledgements

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