Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025 ASEE
Paper ID #49273

Design and Analysis of Automatic Control Systems for First-Year Engineering Technology Students

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Abstract

Control Systems is an academic discipline consistently popular among Engineering students, which has limited popularity among Engineering Technology students. This is the case because of the history of Engineering Technology as a field. For example, the easiest way for most students to study control systems is through majoring in Robotics. Robotics major itself is not new in Engineering but still new in Engineering Technology. It has been studied that Engineering Technology students can possess competitive knowledge and skills in foundational STEM disciplines (including Math). The recent advances in unmanned vehicle technology, particularly in the Artificial Intelligence (AI) spectrum, and Industry 4.0 (I4.0) trends in academia and industry create a demand for more specialists in the field. To facilitate this, both Engineering and Engineering Technology students should be actively involved in Robotics-related classes, such as control systems.

The authors designed and analyzed the behavior of a control system of a semi-autonomous trailer. Different positions of the vehicle-trailer connection sensor were taken as a criterion for analysis. The authors developed a step-by-step guide for first-year engineering technology students to help them design and analyze similar control systems of their own. This paper discusses the manual and the educational assumptions of the authors.

The results of the presented research have a potential for use among both Engineering Technology students and faculty. One goal is to popularize the discipline of control systems among Engineering Technology students by providing an "easy" approach to a basic control systems problem. Another goal is to provide Engineering Technology faculty with an example of how basic control systems problem can be presented to Engineering Technology students. Additionally, this paper can help Engineering Technology faculty to design similar guides for other control system problems.

Keywords: Automatic Control Systems, Vehicle-Trailer Connection, Semi-Autonomous Trailer, First-Year Engineering Technology Students, Artificial Intelligence (AI), Industry 4.0 (I4.0), Robotics, Engineering Technology, STEM

Introduction

A variety of passenger car-trailer connections exist on the market. One specific type of the connections provides a tensile force measurement capability for the purpose of providing feedback for the semi-autonomous trailer's control system. Semi-autonomous trailer is an innovative technology that can encourage drivers to use smaller vehicles for towing, which will contribute to restoration and improvement of urban infrastructure (NAE Grand Challenges for Engineering, 2020). The design of vehicle-semi-autonomous trailer connections is a complex task involving a range of different engineering and non-engineering disciplines. The elements of the design of a control system for a vehicle-semi-autonomous trailer connection are in the focus of the technical part of this paper. A displacement sensor is one element of the control system, which position *may* affect the responsiveness of the trailer's control system (Kuleshov, 2021). The authors considered several different positions of the displacement sensor. The goal was to determine whether or how the position of the sensor impacts the control system.

An example of a vehicle-trailer connection is presented in Figure 1.

Figure 1. An Example of a Vehicle-Trailer Connection.

Note: (https://oshkoshdefense.com/oshkosh-defense-awarded-61-8m-to-produce-trailers-for-the-joint-light-tactical-vehicle-jltv/). Copyright 2021 by Oshkosh Defense, LLC.

The purpose of this paper was to develop a step-by-step guide for first-year engineering technology students to help them design and analyze similar control systems of their own. This paper discusses the manual and the educational assumptions of the authors.

Literature Review

Control systems and robotics are the two components of engineering and technology education that have been rapidly transforming with the advances in technology and computing power since late 1970s and early 1980s. Back in the days, control engineering would be used primarily for space missions, and the word "robots" – associated with exclusively humanoid robots from the science-fiction movies. Controls-focused courses and associated curriculum were commonly referred to in literature as control engineering education (CEE) until mid 2000s (Kheir et al., 1996), when the term started to dissipate. Control engineering, once a special discipline, started to become a part of practically any engineering device or structure. One could find microprocessors anywhere – from a countertop water filter to an unmanned underwater vehicle designed to inspect the pipelines at the sea bottom. At that point industry found itself in a huge demand for engineers with controls background in their backpacks. Academia's response was the introduction of the elements of control engineering to the conventional engineering and technology programs in Mechanical, Electrical, Industrial, and engineering and engineering technology, its deeper integration in Aerospace engineering and engineering technology, and introduction of new programs. Yet, engineering technology programs have a lot to build upon the present achievements in curriculum adjustments. For example, the most recent National Academies report lists only one program each with the words "control" and "robots" in the title (Pearson et al., 2017). The process of making control engineering an integral part of traditional STEM programs and introduction of new programs continues to this day. Moreover, the transformed nature of the new generation of potential students provides additional support for the need of curriculum adjustments (Rossiter et al., 2023).

The knowledge of the basics of control engineering has a potential to shift STEAM students' approaches in problem-solving towards more sustainable paths. If the physics is "the science of the most essential natural phenomena," control engineering is the "science" of the *links* and *interaction* of the elements of the systems representing those phenomena. The knowledge of the basics of control engineering can help students see the cause and effect of things beyond engineering. In other words, the knowledge of the basics of control engineering lays a foundation for both hard *and* soft skills in graduates. The demand for soft skills in STEM graduates is essential for the 21st century economy (Caeiro-Rodríguez et al., 2021; Kuleshov & Lucietto, 2022).

The ongoing Industry 4.0 (I4.0) revolution is giving academia an additional impetus to further develop control engineering-integrated curriculum. All the nine pillars of I4.0 have elements of controls. Some, like Autonomous Robots speak for themselves, while others like Horizontal and Vertical Integration would require graduates to apply *systems* thinking approach to explore, describe, and adjust the existing human-machine industrial systems on the way to transforming them into the new I4.0 environment. The I4.0 demand for new soft and hard skills in graduates makes academic institutions go further and – in addition to curriculum adjustments – become one of the reasons for creating I4.0-oriented programs and majors (Hernandez-de-Menendez et al., 2021; Chaka, 2023; Kuleshov & Lucietto, 2024). The latter is the significant shift, which successful implementation could deliver a new generation of graduates, whose knowledge of control systems would never be questioned by potential employers.

Hence, the following reasons speak for the need of a simple way to deliver the basics of control systems theory and applications for first-year engineering technology students.

- The need for further integration of controls in engineering technology curriculum
- The universal applicability of control systems theory towards real-life problems
- The growing demands of I4.0 revolution

Below is the description of the student guide for the design and analysis of a basic control system using the example of a semi-autonomous trailer.

Description of the Student Guide

1. **Define the Objective**
   - Identify what needs to be controlled
     - Tensile force at the vehicle-trailer connection
   - Determine the desired behavior or setpoint
     - The tensile force must fluctuate within the set amount range

2. **Understand the System**
   - Study the system
     - The system contains of the three main elements as follows
       - The vehicle
       - The vehicle-trailer connection (includes tensile force Sensor)
       - The semi-autonomous trailer (incl Motor)
   - Identify system inputs, disturbances, and feedback link(s), and outputs

  - Inputs
    - The semi-autonomous trailer’s pushing force
  - Disturbances
    - The vehicle’s pulling force
    - Road obstacles (can be eliminated for the purpose of the project)
  - Feedback link(s)
    - The signal from the sensor
  - Outputs
    - The force at the vehicle-trailer connection sensor

- Develop a mathematical model
  - Use differential equations or transfer functions to represent the system's behavior
  - Highlight the limitations of the model

3. Select the Type of Control System

- Open-Loop Control (Without Feedback)
  - The system operates based on a predefined input
- <u>Closed-Loop Control (With Feedback)</u>:
  - The system adjusts the input based on the output
  - The vehicle-trailer connection’s sensor provides the system feedback

4. Choose a Control Strategy

- <u>Proportional-Integral-Derivative (PID) Controller</u>
  - The system “continuously” adjusts the input based on the error received through a feedback link
- On-Off Control
  - The system turns on and off based on the discrete sensor readings
- Feedforward Control
  - The system uses a certain model to predict and correct disturbances before they even affect the output

In the semi-autonomous trailer connection case, we selected the PID controller. PID is an industry-standard solution (Ang et al., 2005), which has predesigned simulation blocks in such computer software packages as MATLAB Simulink. Future authors can consider selecting alternative controllers to replicate and build upon the current study.

In the semi-autonomous trailer connection case, the control happens as follows. The vehicle starts moving; the vehicle-trailer connection sensor sends an excess tensile force signal to the semi-autonomous trailer's motor; the motor starts and increases axle speed to the point when the tensile force at the connection is zero and then *maintains* it within the set amount range when the vehicle is moving.

The position of the sensor depends on the design of the vehicle-semi-autonomous trailer connection. The following are the three types of sensors for three different designs.

1. Load Cell (Integrated)
2. Optical Sensor
3. Potentiometer (Integrated)

The sensor position will impact the signals going into the controller. Students can investigate the noise in the sensor and signal range.

5. Design the Controller

- Mathematical Modeling
  - Derive equations to predict how inputs affect outputs
  - Highlight the limitations of the model
- Simulate the System
  - Use tools like MATLAB Simulink, or Python to simulate and test the controller with the system model
  - Semi-autonomous trailer connection case: MATLAB Simulink

6. Implement the Controller

- Choose hardware for real-world implementation
  - Microcontroller
  - Programmable Logic Controller (PLC)
  - PC-based control
- Write new or adjust existing from a template (where appropriate and applicable) control algorithms in software as defined in the previous steps

7. Test and Refine the System

- Test in a Controlled Environment
  - Validate the controller's performance under varying conditions. Evaluate the system and indicate whether there are differences in

performance, and whether the performance can be the same by tuning the controller.
    - Semi-autonomous trailer connection case: Simulate the test of the system performance for a selection of sensor positions. Consider between three (3) and five (5) distinct positions, and that first single set of controller gains will be used, and then for each of these, the auto-tuning will be used to try to improve it.

- Adjust Parameters
    - Modify tuning or controller logic as needed for the system's expected performance, including stability

- Provide design recommendations to eliminate the noise in the controller
- Incorporate Safety Features
    - Ensure the system operates within safe limits

8. Deploy and Monitor

- Deploy the control system in the real-life settings
- Continuously monitor performance and make improvements

Recommendations for First-Year Engineering Technology Faculty

The authors encourage the first-year engineering technology faculty to use the guide to increase student interest in control systems. The instructors can run an introductory presentation, which would highlight the importance of control systems for the modern-day industry. The presentation can include the most recent advancements in technology, featuring unmanned systems and specifically AI. The presentation can include the overview of I4.0, its pillars, and the detailed description and control applications of the selected pillars. The selection depends on the objective of the course and instructor's background. The instructors should keep in mind that the students come from different backgrounds, and some have limited knowledge of higher mathematics and physics, especially during the freshman year (Lucietto, 2017). Each step of the guide can be adjusted according to the specific audience and their knowledge, skills, and prior experience. The adjustment can either limit or increase the complexity of the steps. The authors recommend running a questionnaire at the beginning of the course and asking students if they are familiar with the specific disciplines or areas of knowledge required to go through the steps of the guide as determined by the instructor. The authors recommend setting up the teams of three to four students for the practical implementation of the control projects. The recommended number of students in teams aims to ensure the diversification of prior knowledge, skills, and experience within a team. The authors recommend running a post-course questionnaire asking about the student experiences in the project and their relation to the topic of control systems. The instructors can use the questionnaire to adjust the project delivery and content for future students in the similar projects.

Discussion/Conclusion

The paper highlighted the reasoning for popularizing control systems among first-year engineering technology students. The concept of "easy" approach to a basic control systems problem can go as far as each individual instructor's enthusiasm and background allows. The recommendations provide engineering technology faculty with an example of how basic control systems problem can be presented to first-year engineering technology students and included specific advice on the project implementation. Engineering technology faculty can use the provided guide as a template for approaching other control system problems.

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