**Lesson Plan:** Introduction to Proportional Integral Derivative (PID) control.

**Course:** ME 4030 (Controls)

**Intended Audience:** Senior level students in ME or EE.

**Pre-requisites:** ME 3050 (Modelling and Analysis of Dynamical Systems) or equivalent.

**Required Materials:** Course notes (available online) and access to simulations.

**Suggested Materials:** Nise, Norman S. *Control systems engineering*. John Wiley & Sons, 2020.

**Description:** This course provides an in-depth introduction to control systems engineering, focusing on modeling, analysis, and design techniques for linear feedback control systems. Topics include dynamic system modeling, system response analysis, stability, time-domain and frequency-domain design methods, and classical control techniques such as PID control. Students will gain hands-on experience with MATLAB/Simulink for system simulation and controller design, applying these skills to real world systems. By the end of the course, students will be able to design, analyze, and implement controllers to meet specified performance criteria in engineering applications. This is a required course in ME curriculum.

**Timeline:** This lesson plan should ideally occur in week 6 of the course. By this time, student should be exposed to the basics of modelling a system, Laplace transforms, representing systems as block diagrams, time domain analysis of the system, understanding stability and basics of feedback control.

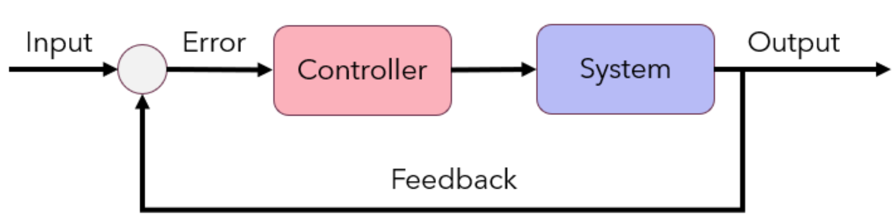
**Applicable ABET student outcomes:**

Source: https://www.clemson.edu/cecas/departments/me/academics/accreditation.html

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
3. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

**Recap of the previous lecture (essential principles of feedback):**

- We can shape the system response using feedback control
- This means that we can take some measurements from the system and design a feedback controller to stabilize the system.



**Learning Objectives**

1. **Identify the performance parameters for a control system:** Students will identify different performance parameters that characterize a control system, such as rise time, settling time etc. (Bloom's level 1 and 2: Understanding and Remembering)
2. **Design a PID controller:** Students will identify the basic components of a PID (Proportional-Integral-Derivative) controller and design one to control a simple system such as a spring-mass-damper system for desired performance characteristics. (Bloom's level 5: Creating)
3. **Analyze the system's response to different PID tuning:** Students will simulate the system with the PID controller, analyzing the system's response and the effects of tuning the PID gains. (Bloom's level 4 and 5: Analyzing and Evaluating)

**Activity 1: Case Study –** Performance Parameter Identification (15 minutes)

*Objective:* Identify key parameters that characterize the performance of a control system.

*Activity for 50-minute lecture:* Example plots (and animations) of a step response obtained from different mechanical systems will be provided and students are asked to label critical performance parameters like rise time, settling time, overshoot, and steady-state error. A summary of each parameter will be provided to reinforce each parameter's significance.

*Activity for 20-minute presentation:* This activity will be condensed to 5 mins where the instructor will use slides to show one case with good performance parameters and one case with bad performance parameters obtained for the same system. Students will identify and reflect on each performance parameter. (The main performance parameters: rise time, settling time, steady-state error and peak overshoot).

**Activity 2: Minute Paper –** PID Controller Design (15 minutes)

*Objective:* Design a basic PID controller.

*Activity for 50-minute lecture:* Students will be presented with a simulation environment of a simple spring-mass-damper system that needs control. Instructor will guide them through selecting basic values for the proportional, integral, and derivative gains to achieve desired performance characteristics. Have students sketch their control logic or rough parameter choices on paper, followed by a group discussion to refine their designs.

*Activity for 20-minute presentation:* This activity will be condensed to 5 mins where the instructor will use the simulation tool (MATLAB) to demonstrate the effect of different control gain (proportional, derivative and integral gains) on the system response. Then, the instructor will identify how each control gain affects the performance parameters. Students will fill out a **minute paper** at the end of this activity.

**Minute paper template for Activity 2:**

Name: ______________________________ Date: ______________

Q1. What was the most important concept you learned from the PID control design demonstration activity?
(Write 1-2 sentences summarizing what stood out to you.)

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Q2. How do proportional, derivative, and integral gains affect system performance? (Provide a brief explanation based on the demonstration.)

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Q3. What questions or uncertainties do you still have about control gains or system response? (List any topics you would like to explore further or clarify.)

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**Minute paper for Activity 2 (expected answers):**

Name: Proportional Pete Date: 12/12/2121

Q1. What was the most important concept you learned from the PID control design demonstration activity?
(Write 1-2 sentences summarizing what stood out to you.)

*I liked the simulation tool used in this activity. It was easy to visualize the effects of each PID control gain and look at the system response directly. This helped me understand the general intuition behind designing a PID controller.*

Q2. How do proportional, derivative, and integral gains affect system performance?
(Provide a brief explanation based on the demonstration.)

*Proportional gain: Reduces the rise time. System tries to go to the set point faster.*

*Derivative gain: Reduces the oscillations. System will settle down faster.*

*Integral gain: Reduces the steady state error. System will converge to the set point.*

Q3. What questions or uncertainties do you still have about control gains or system response?
(List any topics you would like to explore further or clarify.)

*I am not sure how the combination of these different gains will affect the system. Can we explore some real-world applications where PID control is used and use simulations to play around with the gains to see how it affects the system?*

**Activity 3: Simulation based Learning with a Minute Paper** – PID Playground (<u>20 minutes</u>)

*Objective:* Students analyze system responses to PID tuning.

*Activity for 50-minute lecture:* Students work with a simulation environment to analyze the response of a spring-mass-damper system with different PID gain values. They will have the ability to adjust gains and observe the effect on system response. Instructor will facilitate a discussion in the end, focusing on the impact of tuning on performance parameters.

*Activity for 20-minute lecture:* This activity will be condensed to <u>10 mins</u> where the instructor will provide a simulation tool, and students will be provided <u>5 mins</u> to play around with different PID gains and see what happens to the system. Instructor will facilitate a <u>5 mins</u> discussion in the end, focusing on the general intuition for designing PID controllers. Students will fill out a <u>**minute paper**</u> at the end of this activity.

Guiding questions for discussion

1. What is the effect of adding a proportional controller
2. What is the effect of added a derivative controller
3. When do you need an integral controller
4. What is the general intuition to design a PID controller

**Minute paper template for Activity 3:**

Name: ______________________________________ Date: ________________

Q1. What was the most important concept you learned from the PID playground activity? (Write 1-2 sentences summarizing what stood out to you.)

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Q2. Why do you think the controller you designed counts as a good controller (use the performance parameters to evaluate this).

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Q3. Why do you think the controller you designed counts as a bad controller (use the performance parameters to evaluate this).

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**Minute paper template for Activity 3 (expected answers):**

Name: Derivative Dave                Date: 12/12/2121

Q1. Do you feel confident to design a PID controller for a different system? (Write 1-2 sentences explaining your understanding or if you need further clarification.)

*I understood what counts as a good controller vs a bad controller. It also gave me a good intuition on what the design process should look like. I think I can use this idea to design a controller for a different system.*

Q2. Why do you think the controller you designed counts as a good controller (use the performance parameters to evaluate this).

*A good controller makes the system converge to the setpoint in a smooth way with fast rise time, fast settling time and minimum overshoot, no steady state error.*

Q3. Why do you think the controller you designed counts as a bad controller (use the performance parameters to evaluate this).

*The system will never reach the setpoint using a bad controller. It will also have lot of oscillations, large steady state error and overshoots.*

**Formative Assessment (based on Activity 2):**

The below table describes the effect of each component of a PID controller on the system response. Fill in the missing fields with the following options.

| | Rise Time | ________ | Settling Time | ________ |
|---|---|---|---|---|
| Proportional | ________ | Increase | Small Change | Decrease |
| Integral | Decrease | Increase | Increase | ________ |
| Derivative | Small Change | Decrease | ________ | No change |

Performance parameters: Peak Overshoot, Steady State Error

System response: Increase, Decrease, Small Change, No Change

Correct Answers:

| | Rise Time | Peak Overshoot | Settling Time | Steady State Error |
|---|---|---|---|---|
| Proportional | Decrease | Increase | Small Change | Decrease |
| Integral | Decrease | Increase | Increase | Decrease |
| Derivative | Small Change | Decrease | Decrease | No change |

Grading: 10 points for each correct answer (30 points total)

**Summative Assessment (based on Activity 3):**

Design a good PID controller and a bad PID controller for a given system using MATLAB. Explain why it's good or bad based on your understanding of the performance parameters. (students will be provided a MATLAB code to start with). Write a minute paper at the end describing in your own words why it is a good controller vs a bad controller. Hint: use the performance parameters to evaluate the goodness of your controller.

Expected answer: A good PID controller should result in a system response which will stabilize the system at the given set point with good performance parameters. This can include a fast rise time, fast settling time with minimum steady state error and peak overshoot. A possible set of PID gains are (Kp = 10, Kd = 5, Ki = 2). An example of a bad PID controller will not stabilize the system at the set point with bad performance parameters. A possible set of PID gains could be (Kp = 20, Kd = 0, Ki = 10) but there could be multiple possible set of gains that can lead to a bad controller.

Grading: 20 points for good PID controller design, 20 points for bad PID controller and 10 points for minute paper which is graded based on completion, accuracy and depth of reasoning based on the system response and performance parameters.