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Work-in-Progress: Integration of Matlab Live Scripts and Simulink for Teaching Chemical Process Control

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Abstract

Active learning resources for chemical process dynamics and control remain limited. To address this, the authors piloted the use of MATLAB Live Scripts and Simulink in a Chemical Process Controls course during Fall 2024. Simulation enables students to apply theoretical principles to real-world systems. Simulink is widely used in chemical engineering education for this purpose. Live Scripts offer interactive features—such as sliders and dropdowns—that help students explore system behavior by adjusting parameters in real time. In class, Live Scripts are distributed with guiding questions to support active learning, while Simulink allows students to build and test their own models. Methods like think-pair-share are employed to promote collaboration. The full repository of the resources was released on GitHub for use. Each module includes learning objectives and exposition for instruction and self-study.

Introduction

Despite the growing use of active learning across engineering disciplines, including in chemical engineering, there are limited resources related to chemical process dynamics and control. The implementation of active learning in the classroom has been shown to improve student engagement and learning outcomes[1]. Silverstein and Osei-Prempeh incorporated active learning by allowing students to physically engage in laboratory sessions involving the use of real process control instrumentation such as pressure-regulators and programmable logic controllers[2]. Clough sequences the lab sessions starting from basic circuits, instrumentation, process dynamics, standard proportional-integral-derivative (PID) control, and finally to advanced control schemes[3]. Others have used more traditional active learning techniques such as peer learning, gamification, and flipped classrooms[4, 5]. The use of simulation tools is especially compelling for process controls. It enables students to use the theoretical principles of process dynamics and control taught in the class to real-world applications in the chemical engineering domain. Process dynamics can be challenging for chemical engineering students to understand because most of their prior coursework focuses on steady-state systems, often represented by process flow diagrams. In contrast, process dynamics involve transient behavior and process controls rely on block flow diagrams, which represent information flow rather than mass flow. These differences can make the concepts less intuitive for students. Simulation tools, such as MATLAB Live Scripts and Simulink, can help students bridge this gap.

Simulink is a multi-domain, block-diagram-based language that enables users to easily input and manipulate block flow diagrams. Simulink is a standard tool in industrial controls work due to its advanced functionalities. Simulink has traditionally been used in many universities to teach process control applications[6]. MATLAB Live Scripts are interactive documents that enable users to embed MATLAB code into a text document, allowing for a seamless blend of computation, explanation, and presentation. MATLAB Live Scripts have emerged as a useful tool in teaching control theory in other disciplines, such as mechanical engineering[7]. MATLAB Live Scripts' functionalities are helpful for instructors by allowing for the quick adjustment of model parameters to demonstrate different system dynamics.

In this work, Simulink and MATLAB Live Scripts were implemented into the Process Controls and Dynamics course at the University of Delaware in the Fall of 2024. In every lecture, a simulation component was incorporated. This approach aimed to bridge the gap between the theoretical understanding and practical applications by making the complex concepts more accessible and engaging. In the following sections, we discuss the methodology for utilizing these simulation tools in the course, the implementation of these tools in class, recommendations for other educators, results, and conclusions.

Software Implementation

Live Scripts have been implemented to enhance instruction and student engagement in control theory education. Unlike Simulink, where students need to build block diagrams to explore models, live scripts provide pre-written code, allowing students to focus on the system's behavior and analysis. Live Scripts offer advanced graphic generation capabilities, which make presenting and interpreting results more straightforward and visually appealing compared to Simulink.

One example use of Live Scripts is in exploring process dynamics. For example, when analyzing a first-order plus time delay model (FOPTD), parameters such as the time constant (τ), time delay (α), and process gain (K) can be linked to interactive sliders within the script as shown in Figure 1. The learning objective in this context is for students to understand how each parameter impacts the system’s response. By manipulating the sliders, students observe how the system response changes with different parameter values. The hands-on process allows students to develop an intuitive grasp of the model's behavior. The live script helps accomplish this by presenting the results in a clear and immediate manner, eliminating the need for students to wait for separate simulations or manually updating models in Simulink for each set of model parameters.

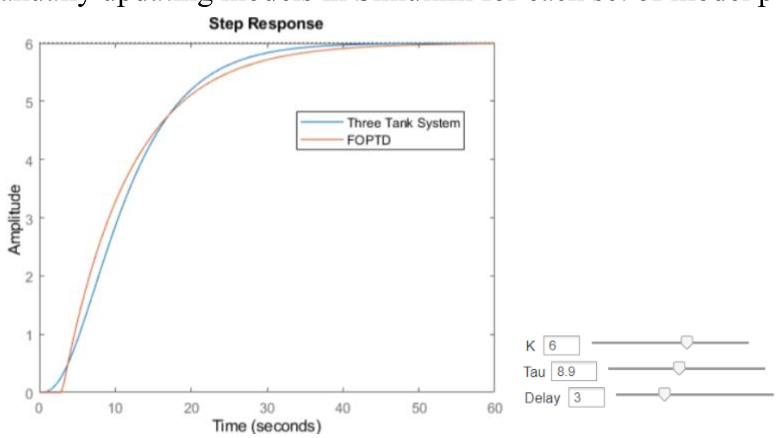

Figure 1. MATLAB Live Script for using a first order plus time delay model to approximate a three tank in series system utilizing interactive sliders to determine model parameters.

The previous example can be extended for multiple concepts. For example, the interactive sliders allow students to iteratively refine parameters to match the behavior of an unknown process, making it effective in process identification exercises. In addition to exploring process dynamics, the example in Figure 1 illustrates how a FOPTD model can be used to approximate a three tank in series system. Beyond process identification, this methodology is equally valuable for exploring concepts such as first-order dynamics, second-order dynamics, and lead-lag systems. By directly manipulating parameters and observing the immediate impact on system behavior, students gain a deeper and more intuitive understanding of these fundamental process dynamics. This approach increases student engagement by allowing them to interact with the model instead of simply presenting the different characteristics of each system type.

Another implementation of MATLAB Live Scripts enables instructors to quickly demonstrate and compare various models or tuning strategies. For instance, educators can use a live script to transition seamlessly between PID tuning rules such as Cohen-Coon, Ziegler-Nichols, IMC, and Direct Synthesis. This flexibility allows instructors to show the impact of different tuning rules on system performance in real time, helping students grasp the effects of each method without requiring multiple Simulink models. The clean presentation of results within the live script further aids in understanding, as graphs can be formatted for clarity and ease of interpretation enabled by MATLAB's plotting functions.

Simulink

Simulink's advantage, particularly for teaching advanced examples, is that its block diagram approach minimizes programming complexity while providing an intuitive and visual way to model control systems. This makes it especially effective for in-class exercises where students learn to construct block flow diagrams required for advanced control schemes. For instance, block diagram algebra, an introductory topic, can be taught effectively in Simulink by demonstrating the effects of having transfer function blocks in parallel and in series, helping students grasp these fundamental concepts required later in the course.

Simulink provides the flexibility for students to create their own models and transfer functions with unique structures. This feature, while possible, is more challenging to achieve in MATLAB Live Scripts, where pre-written code tends to limit exploration without using multiple functions that students may be unfamiliar with. For example, demonstrating the concept of closing the control loop is far easier and more intuitive in Simulink, as the visual feedback of connecting blocks conveys the process clearly. In contrast, accomplishing the same in MATLAB requires entirely different functions and lacks a visual component.

Simulink is useful for performing virtual experiments that would be difficult to duplicate in MATLAB Live Scripts. For example, students can use Simulink to determine the parameters of the Relative Gain Array (RGA) through virtual experimentation. The open loop model for a liquid tank with hot and cold stream mass flow rate inputs with liquid level and temperature outputs for the virtual experiment is shown in Figure 2. Using the experimental outputs, they can determine the experimental relative gain array parameters. They can then compare these experimental parameters with those obtained through theoretical manual calculations, reinforcing their understanding of RGA concepts. These virtual experiments provide an interactive and engaging way for students to bridge theoretical knowledge with practical experimentation.

In Class Implementation

The course met twice a week. Each session dedicated 1 hour to theory and 20 minutes to simulation exercises using Simulink, allowing students to immediately apply concepts covered in lecture. At the start of the semester, students were encouraged to collaborate in groups to build familiarity with the software. Working together allowed students to compare model behavior by applying different parameters and exploring system dynamics. This structured experimentation enhanced engagement, strengthened problem-solving abilities, and aligned with the course's learning outcomes. Teaching assistants were present in class to help troubleshoot and guide students.

Homework combined manual calculations and simulation tasks. Textbook problems were expanded with simulation components to validate solutions or extend understanding. For example, class exercises introduced control strategies such as ratio, feedforward, and feedback control, but only feedforward was fully covered in class. Students then applied the remaining strategies independently in their homework to reinforce learning beyond the classroom. Students also completed a Simulink project based on *Process Control: Modeling, Design, and Simulation* by Bequette[8]. The project required system modeling, controller tuning, and dynamic analysis, bridging theoretical understanding with practical skills.

This structure complements a flipped classroom model. Rather than passively watching pre-recorded videos, students actively engage with exercises guiding them through theory while applying it in real time. Integrating Simulink and Live Scripts during class enables students to immediately connect concepts to practice, avoiding the delay of separate recitations or labs. While additional sessions can still add value, live integration accelerates understanding by closing the gap between learning and application, helping students retain and apply concepts more effectively.

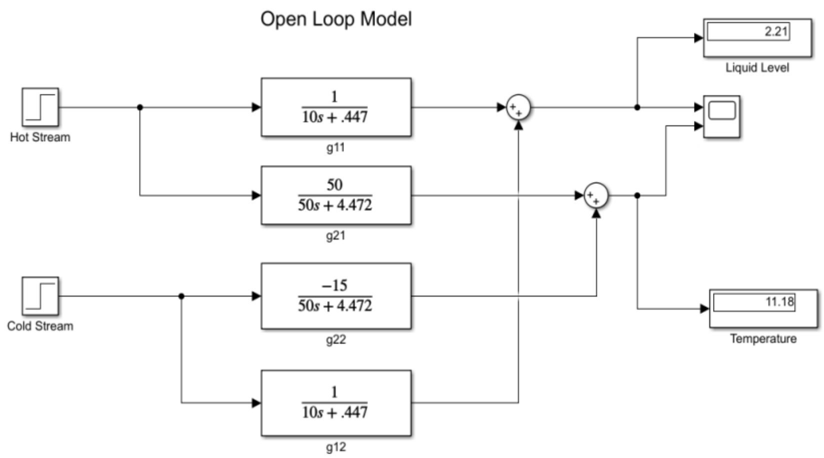

Figure 2. Simulink Open-Loop model for a liquid tank with a hot and cold stream flow rate inputs with liquid level and temperature measurements.

Recommendations

Given the distinct advantages of both Live Scripts and Simulink, we recommend that instructors use these tools based on the specific learning objectives of the course. Live Scripts are effective for understanding model parameters due to their interactive sliders, dropdown menus, and advanced visualization functionalities. These features make them suitable for teaching concepts such as process dynamics, where students benefit from directly manipulating parameters and observing real-time changes in system responses. Simulink is valuable for its relevance with industry practices and its ability to support teaching students to construct block flow diagrams, a skill that is not always intuitive. Simulink also excels in handling more complex control schemes without requiring significant programming expertise, making it simpler for students.

Live Scripts offer the advantage of being less time intensive, as the models are pre-set and require minimal setup by students. Simulink's block flow diagram model construction can deepen understanding in cases where learning the controls structure is the learning objective. Setting up models in Simulink may not always be the best use of class time. To address this, instructors can provide pre-built Simulink models for students to download and explore when the setup process is not central to the learning objective. For topics such as feedforward, feedback, cascade control, and multiple input multiple output (MIMO) models, and closed loop controls, additional time in class may be valuable for the visualization aspects in Simulink.

Ultimately, the choice of tool should be guided by the desired learning outcomes. For example, we recommend using MATLAB Live Scripts when the focus is on parameter exploration, system comparison, or visualization. For teaching advanced control schemes, Simulink with a hybrid approach can be effective: cover one example in class to demonstrate the concepts and assign the remaining examples as homework.

Results

The MATLAB Live Scripts and Simulink models developed for the course are publicly available on GitHub: https://github.com/dhuynh10/ASEE-Draft/tree/main. The repository is organized by topic, with each module corresponding to a core concept in the course (e.g., first-order systems, feedback control, dynamic modeling). Each folder contains one or more Live Scripts and/or Simulink block diagrams that directly align with specific learning objectives.

All Live Scripts are fully self-contained, allowing students to independently review theory, run simulations, and complete guided exercises within the same document. This structure supports both in-class and self-directed learning. Simulink models are paired with the scripts and designed to be modifiable, enabling students to explore variations or faculty to tailor models to their own curriculum needs. The content is intended to serve as both a teaching resource for instructors and a reference for students. Faculty may selectively remove or keep explanatory material depending on the level of scaffolding desired. The repository is continuously developed, and future iterations will include expanded coverage of advanced control strategies and additional case studies.

Conclusion

This work focuses on the integration of MATLAB Live Scripts and Simulink into the Process Dynamics and Controls course. Both tools have been shown to be applicable towards in class active learning exercises. Live Scripts are effective for helping students to visualize multiple different models simultaneously as well as vary model parameters to understand process dynamics. Simulink is suitable for advanced process control models and for learning objectives that require a strong understanding of block diagram interactions. The tool used for any given concept should be based on the learning objectives. The implementation of the tools for the University of Delaware's process dynamics and controls class for 2024 was discussed with examples. Furthermore, the author plans to continue to develop chemical engineering relevant controls examples for MATLAB Live Scripts and Simulink to be released.

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