Practical session for designing a PI controller with a minimum-order observer in a linear system

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EXTENDED ABSTRACT

1. INTRODUCTION

Control engineering is a multidisciplinary field that many students find challenging due to its abstract nature. To enhance learning, a balance between theoretical knowledge and practical sessions is essential, as active learning and hands-on experience improve comprehension, particularly in abstract concepts. Educators aim to prepare students for real-world applications in industrial settings, where they need to integrate control theory across various disciplines like electrical, mechanical, and chemical engineering. Traditionally, control engineering courses focus on modeling, simulation, and control system design, making these skills crucial for students' future careers in industry [1,2].

Recent developments have explored the use of virtual and low-cost laboratories as alternatives to traditional setups, especially in light of the COVID-19 pandemic. Virtual labs offer cost savings but may limit hands-on experience, while low-cost labs using tools like Arduino and Raspberry Pi allow students to experiment with real systems. These setups have been shown to boost student engagement and provide practical experience with controller design and observer systems. Additionally, programmable logic controllers (PLCs) and data acquisition (DAQ) cards offer ways to reduce equipment costs while maintaining effective practical sessions. The study proposes a practical session where students model a second-order system and design a PI controller, enhancing their understanding of real-world industrial applications.

2. METHODOLOGY

The simulated controlled system used was made by LD Didactic®. As represented in Fig. 1, number 1 corresponds to the power supply of +15 V, 2 to the voltage input to the system, and 3 to a disturbance variable z (+2 V DC) that can be supplied by pushing the red button. Numbers 4 and 5 in the same Fig. 1 show the sensor output (0-10 V) considering second- and first-order systems, respectively. In this study, a second-order system was used (Fig. 1). Number 6 in Fig. 1 shows the compensation times measured in s. Both were set to 10 for this study. The USB-6009 DAQ from National Instruments® was used for both the input and output of the system. The experimental run was carried out with a 3 V supply. The time of the experimental run for data acquisition was around 100 s as the response was steady at that time. The sampling time was set at 0.1 s. In order to use the USB-6009 DAQ with Matlab/Simulink®, an NI-DAQmx driver was installed. The experimental run was divided into the following stages: data acquisition, modeling, PI regulator with minimum-order observer design by pole placement, and application of the PI regulator to the experimental system to evaluate the obtained results. Note that the analogical output of the DAQ is limited to 0-5 V.

3. RESULTS AND CONCLUSIONS

The parameters obtained in the identification were K 1.04, 1 (s-1) 13.53, 2 (s-1) 8.83 and d 1.9810-4 (Eq. (1)). The model fitted quite well as the system is linear. Students have to design the control system taking into consideration the model obtained and, subsequently, the results on a real system have to be assessed. Students have to evaluate the characteristics of the response by comparing the simulated system with the real one. It can be observed how the input was saturated at 5 V during the first 10 s. From this Figure, students can see the difference between the simulated and real control.

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -8\times10^{-3} & -0.19 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 8.7\times10^{-3} \end{bmatrix} u(t)$$
$$y(t) = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} \quad (1)$$

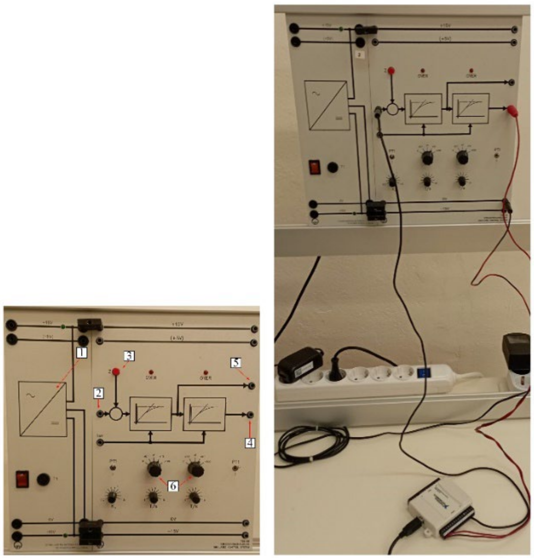

Figure 1. Practical setup with second-order system and National Instruments USB-6009 DAQ card.

4. POSSIBLE EXTENSIONS

As a DAQ system for a physical system module from L-D Didactic® has been prepared, this setup can be used with other physical systems and to develop more advanced control strategies using Matlab® and Simulink® environments. For example, the setup can be used for nonlinear systems [3] and/or multiple-input multiple-output (MIMO) systems, etc. It can also be used by degree or master's students to carry out their experimental diploma works.

5. CONCLUSIONS

The authors propose a practical session for control engineering students, focused on a second-order linear system to introduce them to real-world system modeling and control. The experimental kit is inexpensive and easy to prepare, allowing students to use Matlab®Simulink® to model the system and design a PI controller with a minimum-order observer, which requires basic programming skills.
This study aims to upgrade an existing experimental setup to enhance students' understanding of core control theory concepts. The upgraded setup allows for a variety of practical sessions related to control engineering, needing only a power supply and the LD Didactic® plant.

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