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Using Apps for Teaching Process Control Classes

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Abstract: Process Control classes focus on theory, with some education laboratories included where the student got some direct steps to work through. Thus, limiting the learning experience and the involvement of all students as the laboratories are run in groups. The temperature control labs produced by companies such as IJ Instruments and APMonitor offer the possibility of students working individually on process control experiments and gaining a more conceptual understanding of process control. However, considering that both control labs are using a GUI to control a small unit connected through a USB cable, the students are not gaining psychomotor skills anyway. This paper demonstrates that app-based control simulators can be an effective alternative to traditional laboratory experiments for teaching process control. App-based simulators can provide students with the same learning outcomes as traditional experiments, such as modeling systems, analyzing PID controllers, and designing feedback controllers. Additionally, app-based simulators offer several advantages over traditional experiments, including, Individualized learning, Flexible experiments: Students can easily change the parameters of the system and experiment with different control strategies, Varied experiments: A wide range of experiments can be created using app-based simulators, Cost-effective: App-based simulators are inexpensive to develop and use. The paper concludes by discussing the potential of app-based control simulators to revolutionize process control education. App-based simulators can make process control education more accessible, affordable, and effective. They can also help to prepare students for the challenges of working in the process control industry.

Keywords: Process Control Education, PID Control, Learning Objectives, MATLAB® App.

1. Introduction

Laboratory experiments are an integral part of any engineering education, which is highlighted in the accreditation requirements for accrediting bodies such as EAB (from the Engineering Council UK) and EAC (from the Board of Engineers Malaysia). The Chemical Engineering labs take the form of group work running through experiments that aim to demonstrate fundamental Chemical Engineering principles, such as fluid mechanics, thermodynamics, reaction engineering, unit operations, and process control. Though EAC keeps pushing for open-ended labs most of the experiments are a matter of following strict guidelines, commonly missing desired learning objectives such as to experiment, learning from failure, and creativity of the 11 objectives listed in [1].

These shortcomings have been particularly addressed in Process Control cases where a traditional control setup such as Training system temperature control produced by GUNT [2], will allow the students to work through the major objectives, but usually leaves some of the students only peripherally involved. This has brought out the home-based learning modules that enable the students to gain hands-on experience to reinforce the key concepts in process control. The most widespread to the authors is the APMonitor Temperature Control Laboratory (TCL), which is a ready-assembled control kit based on Arduino and connected to MATLAB® and Python via USB [3]. Though there were Arduino-based approaches for process control reported earlier, the ready-made kit made the focus more directly on process control, though admittingly losing some of the psychomotor skills. Though the APMonitor TCL is the major ready process control kit, it was not the first. In 2012, the IJ-6 Software-based Temperature Controller was launched and adopted by UK universities such as Heriot-Watt University [4]. The controller comes with its control software, with the GUI shown in Figure 1. Though not as versatile as the APMonitor approach, it allows our students to do Graphical Fit, Regression, Closed Loop Tuning, and for the students to monitor PID controllers' performance. The data is exported as a text file and the students use Excel for analysis and figures. The major advantage of the APMonitor kit is the ease of implementation of Model Predictive Control and its higher versatility due to its two heaters and two sensors, but the IJ Instruments kit is more than enough for a first process control course.

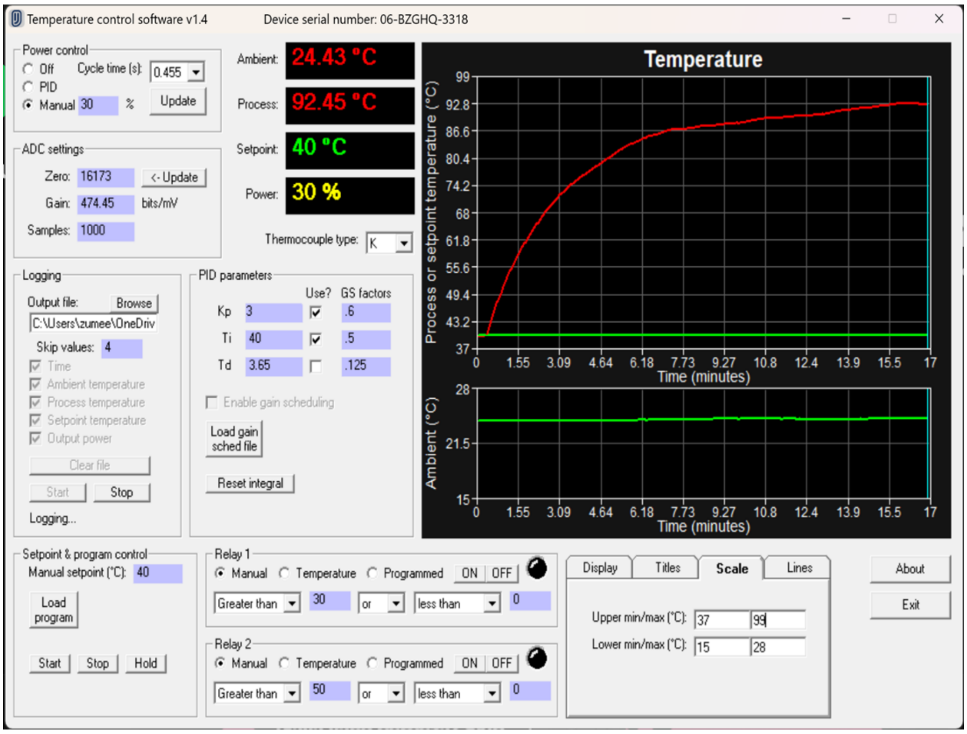

Figure 1. IJ-Instruments control software GUI (showing a step change in the controller output).

In this paper, we discuss our experience in using an App to perform the tasks that were performed using ready-made kits or other individual kits based on Arduino or Raspberry platforms. Demonstrating that an app covers all parts needed for a first control course.

2. Materials and Methods

The reason for the development is that we were using the IJ instruments kit for our year 3 Control II course. However, during the COVID pandemic we could not distribute the kits to our students, and thus needed an alternative assessment. It was agreed that the best way to maintain the learning outcomes for the assignment was to develop an app. MATLAB® was chosen as the it was considered as the easiest way of getting started with app, and all the students had access to MATLAB® through the university license.

2.1. App setup and considerations

To start with the GUI was done by recreating the parts that were commonly utilized in the IJ Instruments GUI as seen in Figure 2. Removing features like thermocouple calibration, relay and alarm-related features, and program control. Next, a process must be simulated in the application, were a second order with dead-time model was modelled from the IJ instrumentation controller as seen in (1)

$$G_p(s) = \frac{Ke^{-t_0 s}}{(\tau_1 s+1)(\tau_2 s+1)} \quad (1)$$

where all variables are defined in the standard way. However, as those who have modelled these cases know, the results become too neat and do not mirror the real behavior. As put in [5] the app is "lacking the level of natural variation, and therefore students do not become familiar with poor or uncharacteristic data". This was achieved by adding a random value generator that creates a 5% measurement error on the temperature shown in the GUI as well as the data exported. The kits had a natural variability, which means no student would do the same as another student. Even in the cases when students had to use the same kit variability would occur due to the ambient temperature. To bring the variability into the app as well, a list of possibilities was created linked to a student number (as can be seen through the selector next to the Start button in the GUI in Figure 2), were small variations in the K, t_0, τ_1 and τ_2 were created to add variability. On top of that, the ambient temperature is randomized in the range of 22-°C when starting the app. The app installation file was shared with the students for the assignment. The students need to have MATLAB® 2018b or later installed, but no additional libraries to run the app, or to use MATLAB® online.

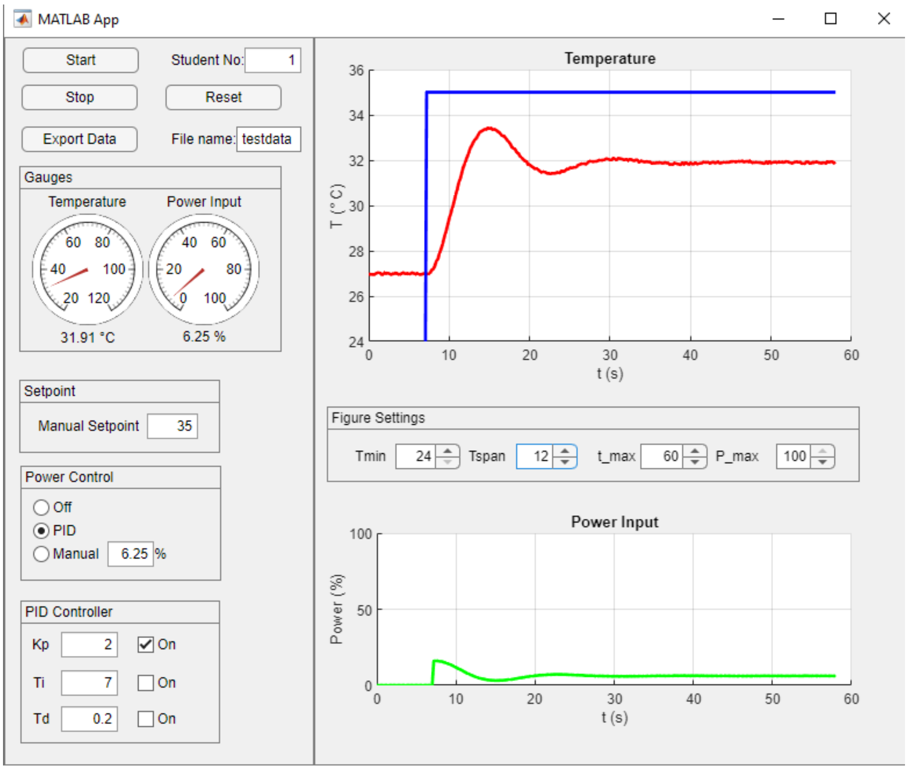

Figure 2. GUI for the MATLAB® App. (Showing a set-point change for the Temperature)

3. Results and Discussion

Firstly, the comparison between the App and IJ instruments running is compared to highlight similarities and differences, then we will look at additional possibilities for use of Apps in process control.

3.1. Tuning of controllers.

From Figures 1 and 2, though they do not show the same magnitude of input change, the readings show a similar level of uncertainty where there are fluctuations in the readings. The difference is not as apparent in the downloaded and processed data as demonstrated in Figure 3. The difference comes from the sampling time which has some limitations and thus cannot catch the full data set. However, the task of model identification based on the step-change poses a similar challenge as the only major difference between the datasets is the settling time. The gain in this case is affected by the difference in ambient temperature, as that leads to differences in power requirements at 40°C.

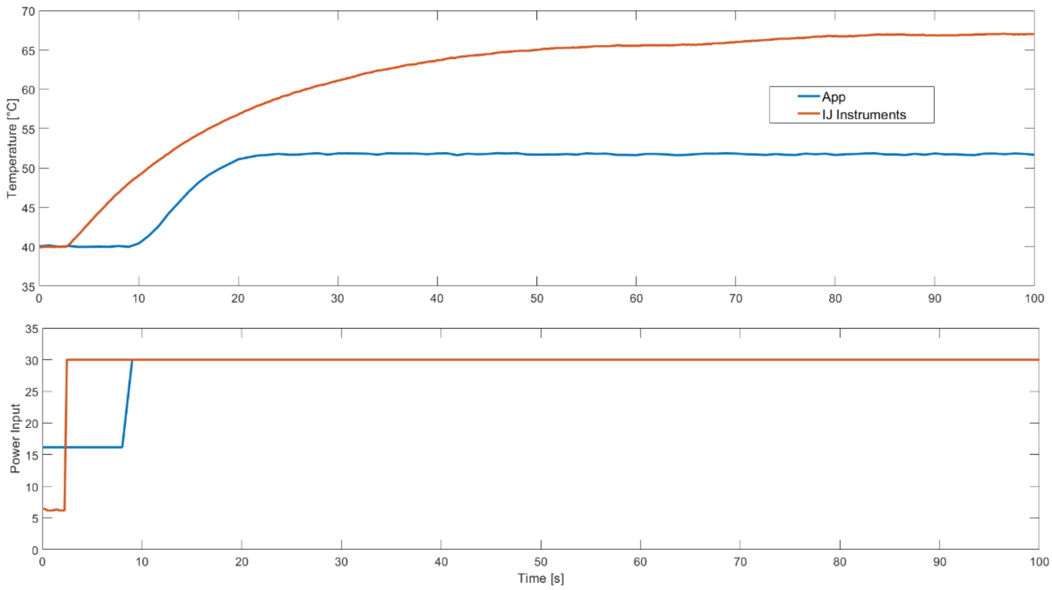

Figure 3. Step testing at 40°C for a step change to controller output of 30% Power.

The other way of empirically obtaining information of the process to tune the controller is the closed-loop method, where maintained oscillations after a set-point change is sought. The ultimate gain tests are shown in Figure 4 for both the IJ Instruments kit and the app, there are more distinct (higher amplitude) oscillations for app, but what it shows that the maintained oscillations is not as symmetric nor as quick to settle as the examples we present to them in classes. If the K_c is reduced by 5% it would usually take 500 seconds to be sure that they are in the underdamped region

The students are then asked to tune the controllers based on the two tests, in Figure 3 and 4, respectively. As the closed loop tuning method is so closely related with Ziegler-Nichols the tuning used by the student is based on their relationships. The open lop tuning, in Figure 3, are based integral time square error (ITSE) for setpoint change. The students are then asked to implement the two controllers then discuss the differences between the two controllers and why they are different.

The figures show that the technical differences between the App and the IJ Instrumentation kit are mostly in some of the responses. As the kit is a matter of plugging the temperature controller to the computer and running it, there is no real loss in psychomotor skills as the IJ Instrumentation as well as the APMonitor temperature controllers do not contain any major psychomotor steps. When it comes to student learning there has been no major difference in the students score based on whether using App or a kit. The major feedback difference is that the students who used the App were more prone to complain about it being time-consuming to run the tests. The App is faster, but it feels longer when it is just an App compared to knowing something happening in real life.

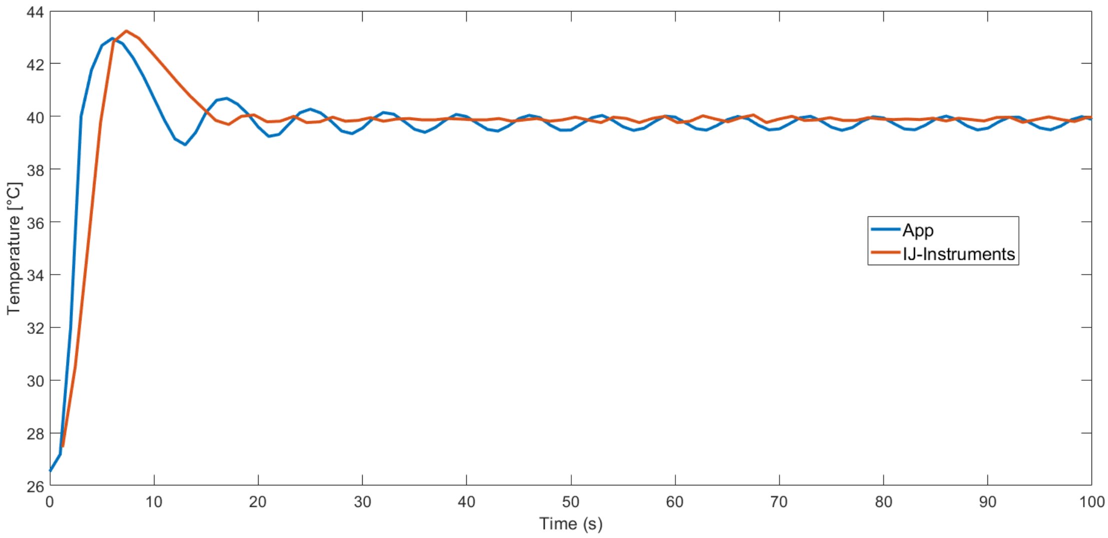

Figure 4. The last step of the closed loop testing.

3.4. Further uses of apps in Process Control

The behavior for the temperature controller cases was very direct as a change in the power input creates a very quick effect on the temperature. An App based on a CSTR with the exothermic reaction A → B was also implemented. As seen in Figure 5 this is a much slower system and the controller has a reversed action compared to the temperature controller.

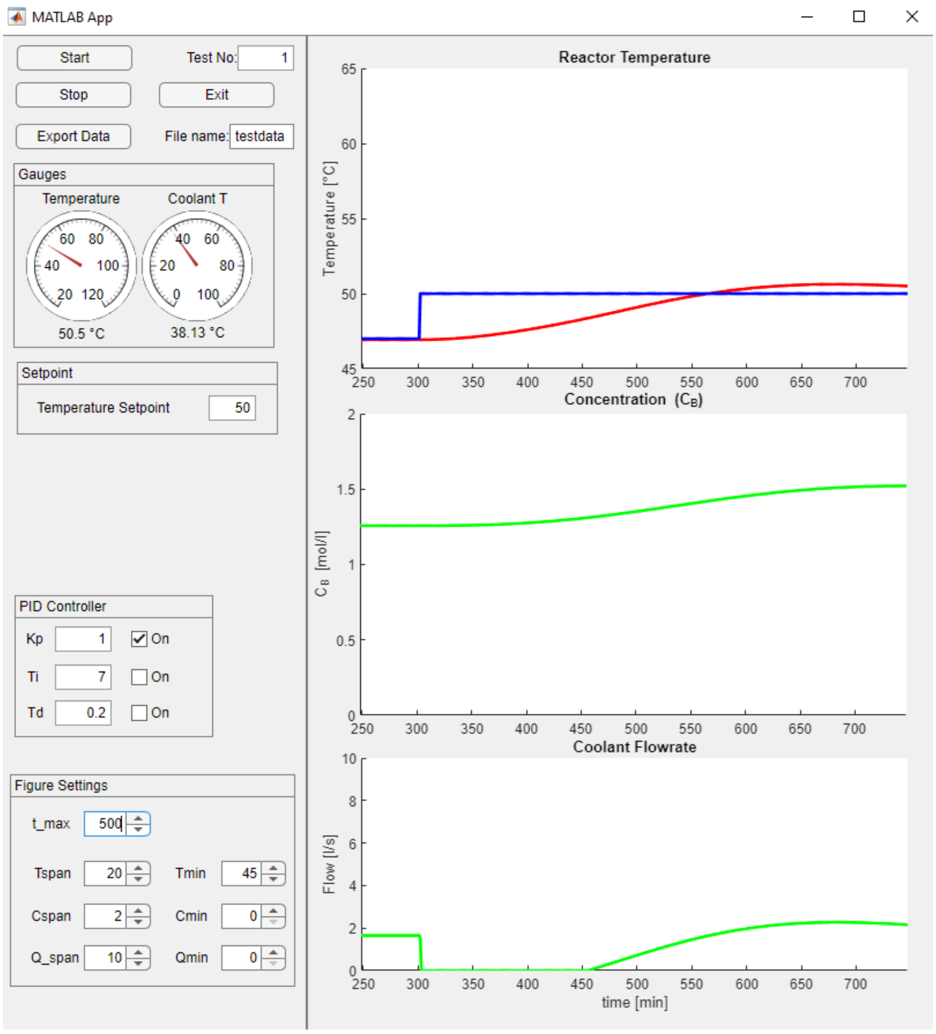

Figure 5. CSTR control for exothermic reaction with Temperature via cooling water.

The App in Figure 6 was developed to demonstrate the multivariable distillation system and the problems relating to that. However, the advanced control course that dealt with multivariable control was discontinued before the App was completed. It was instead used as an open-ended lab during the COVID pandemic lock down.

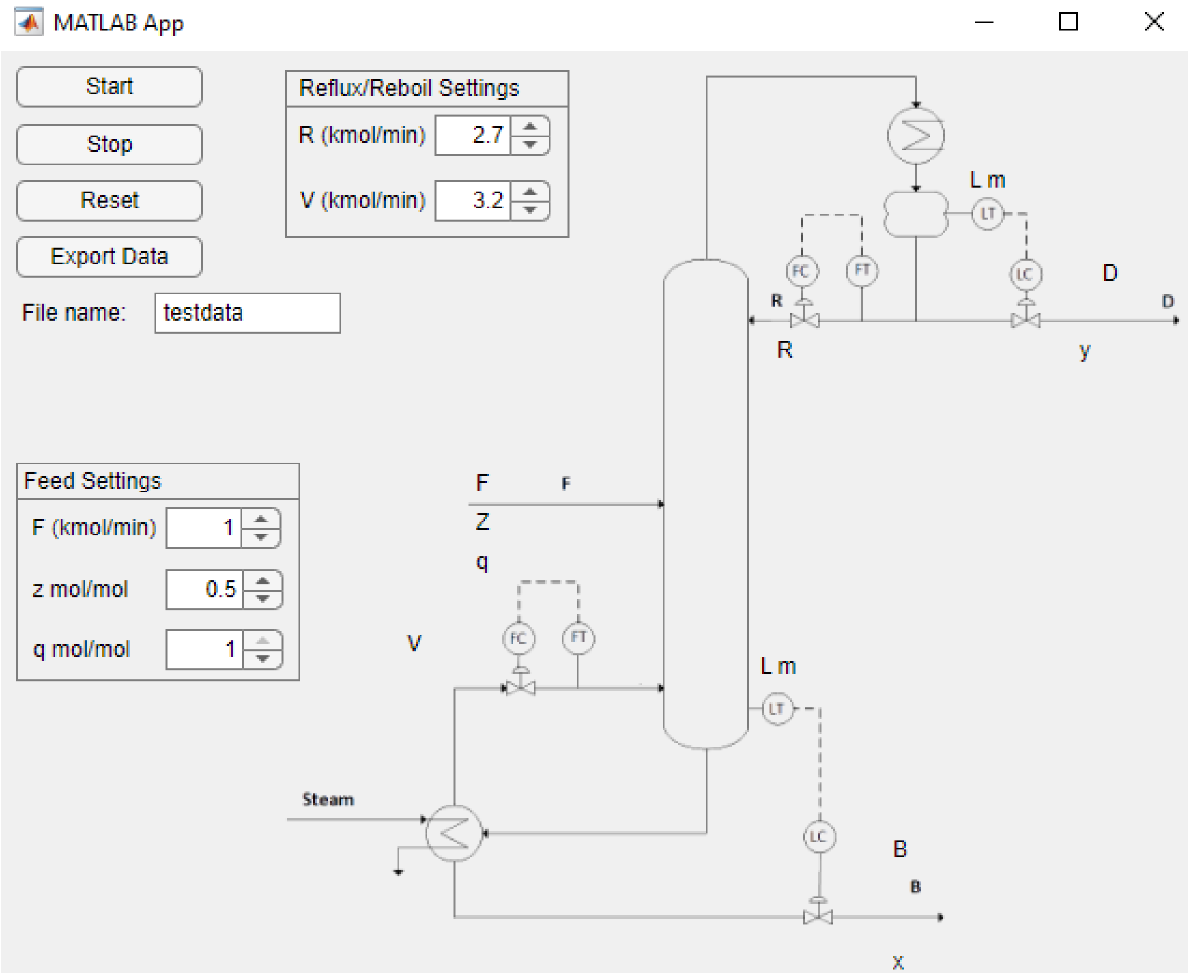

Figure 6. Distillation system for online lab.

4. Conclusions

The paper discusses the potential of app-based control simulators in process control education. The app-based simulators can provide students with the same learning outcomes as traditional experiments, while also offering several advantages, such as individualized learning, flexible experiments, and cost-effectiveness. There is however a note that we should not go all the way and just rely on Apps as they bring limited psychomotor skills. Apps

The authors also present their experience in using an app to perform the tasks that commonly were performed using ready-made kits or other individual kits based on Arduino or Raspberry platforms. They demonstrate that an app covers all parts needed for a first control course. The authors conclude that app-based control simulators have the potential to make process control education more accessible, affordable, and effective.

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