

Simulation of Control of a CSTR Process*

SRINIVAS PALANKI

Department of Chemical Engineering, FAMU-FSU College of Engineering, Florida State University 2525 Pottsdamer Street, Tallahassee, FL 32310-6046, USA. E-mail: palanki@wombat.eng.fsu.edu

SOUMITRI KOLAVENNU

Honeywell Technology Center, Honeywell International Corp., Minneapolis, MN, USA

In this paper, the development of a software module to run a simulation via the Internet is described. The software module is developed in MATLAB/SIMULINK and simulates a regulation problem in a continuous stirred tank reactor (CSTR) in which a series reaction is occurring. The user has the option to input a wide variety of system parameters, initial conditions, final time, and controller parameters. The effect of changing these values on the overall system dynamics can be studied easily. The development of such modules eliminates space, time, and cost constraints and serves as a useful teaching aid.

INTRODUCTION

IN RECENT YEARS, a number of computer-based packages have been developed to augment a traditional lecture-based course. Some examples of such computer packages can be found in Control Systems [1, 2] and in Circuits Design [3]. Since engineering is a hands-on profession, practical experience with real processes is desirable for quality education. However, laboratory equipment is expensive. Usually it is necessary to have multiple modules of the same hardware to accommodate all the students enrolled in a class. This is often not possible due to limited resources. In addition, due to the synchronous nature of experimental work, scheduling laboratory hours is a difficult task, especially in light of the recent trend of working adults going back to school part-time.

Some of the above problems can be solved using concepts of Interactive Distance Learning. These concepts include the use of remote computer access to enhance self-paced learning. The Internet provides a real-time link that eliminates space-time constraints: *it gives access from anywhere at any time*. Moreover, due to the multiuser-multi-tasking nature of computer environments, several students can run the software module at the same time. The development of a **virtual laboratory** has the potential to deliver experiences which are not accessible to students in the real world. Recent technological advances in computer software are bringing virtual laboratories within the reach of educational and student budgets. However, the knowledge base of how to effectively apply this technique to technical education must first be established.

DESCRIPTION OF VIRTUAL CHEMICAL REACTOR CONTROL MODULE

We have developed a prototype module that students can access via the World Wide Web for running a simulation of a chemical reactor. This simulation is used as part of the Process Control course taken by chemical engineering senior students. The simulation involves the design of controllers for regulating the concentration of a continuous stirred tank reactor in which a series reaction $A \rightarrow B \rightarrow C$ is occurring. The reaction $A \rightarrow B$ is a first-order reaction with respect to the concentration of species A with rate constant k_1 and the reaction $B \rightarrow C$ is a second-order reaction with respect to the concentration of species B with rate constant k_2 . The dynamics of the CSTR are given below:

$$\frac{d}{dt} \begin{bmatrix} C_A \\ C_B \\ C_C \end{bmatrix} = \begin{bmatrix} -k_1 C_A - \frac{F}{V} C_A \\ k_1 C_A - k_2 C_B^2 - \frac{F}{V} C_B \\ k_2 C_B^2 - \frac{F}{V} C_C \end{bmatrix} + \begin{bmatrix} \frac{F}{V} \\ 0 \\ 0 \end{bmatrix} C_{Ain}$$

$$y = C_C$$

Here, C_A , C_B , C_C are the concentrations of species A, B, and C, C_{Ain} is the feed concentration of species A, F is the volumetric flow rate; V is the reactor volume. It is assumed that the concentration of species B and C is zero in the inlet stream. The objective is to control the concentration of species C to a desired set-point by manipulating the concentration of A in the inlet stream. The block diagram of the process with an output feedback controller is shown in Fig. 1.

The software module is written in MATLAB/SIMULINK and runs remotely via the Internet.

* Accepted 22 February 2003.

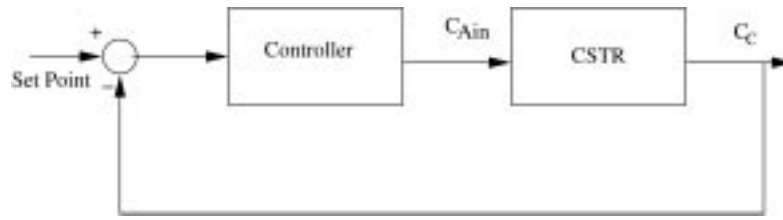


Fig. 1. Block diagram of feedback control loop.

The process is nonlinear due to the presence of a second-order reaction. However, the software has the option to select a linear model or a nonlinear model where the linear model is obtained via a Jacobi linearization of the nonlinear model around the desired steady state. The program uses a MATLAB web server and any student logged into our College of Engineering server essentially gets a copy of the software module on his/her computer. It is preferable to run the program on the web server, rather than on individual computers to ensure that all students are running the same version of MATLAB. Furthermore, this allows the instructor to restrict access to this software to registered students in the college.

In the opening screen, the user can click on the 'Instructions' button to get a brief background of the experiment as well as instructions on how to use the software module. By going to the 'Systems' menu, the linear or the nonlinear model can be selected. This results in a screen shown in Figs 2a or 2b. If the linear model is chosen, then the controller of choice is a proportional-integral-derivative (PID) controller. The system parameters (reaction rate constants k_1 and k_2 , space velocity F/V), the initial conditions (initial concentrations of A, B, and C in the reactor), as well as the final time can be chosen by the user. These can be set by either using the sliders or by typing the desired values in the text box. The minimum and maximum permissible values for the parameters, initial conditions and final time are displayed on either side of the sliders. This is done to prevent the user from inputting values that lead to physically unrealistic situations (e.g. negative concentrations). The user has an infinite combination of parameters to choose from; this ensures that each student conducts a slightly different experiment. Furthermore, the students can study the effect of changing systems parameters and initial conditions on the controller design. Once the system parameters, initial conditions and final time are chosen, the students input the values of the PID controller parameters.

If the nonlinear model is chosen, the students can either choose a PID controller or a nonlinear controller. The nonlinear controller has a multi-loop structure where the inner loop is a state feedback that makes the input/output relationship linear and the outer loop is a pole placement controller [4]. The system under consideration

has only one pole to be placed and the user specifies where this pole should be placed as shown in Fig. 2b.

Once the system's parameters, initial conditions, final time, and controller parameters are set, the user can view the SIMULINK diagram, run the simulation or view a movie of the simulation by clicking on the 'Simulink', 'Movie', or 'Simulation' buttons respectively. Figure 3 shows the Movie option. In this option, the concentrations of A, B, and C appear as bar graphs. The species A, B, and C are represented in red, green, and blue colors respectively. The color of the reactor is a composite color obtained by computing a weighted average of the three colors using the instantaneous concentrations of A, B, and C as weighting functions. Thus, the reactor color can visually indicate if the reactor has reached the desired specification. Furthermore, a plot of the concentration of species C with time along with the desired set-point is provided. The Simulation option provides only the plot of species C with time along with options to print the graph and save the data as shown in Fig. 4.

EVALUATION

The module has been used in the Process Control course since 1999. The student response has been overwhelmingly positive. This experiment can be run by the students from any computer on campus and at any time. Furthermore, the students tended to repeat the simulation many times using different values of the system parameters, initial conditions, final time, and controller parameters which led to a deeper understanding of the overall dynamic system behavior. Our experience in the past in teaching this course has been that if the students are asked to write their own code to do such a simulation study, they tend to spend so much time debugging their programs that there is not enough time to run the program under different conditions to understand the behavior of the system. The availability of this module removed the burden of writing computer code to run the simulation from the students. Finally, there was tremendous learning reinforcement when the students successfully implemented a control strategy on this module.

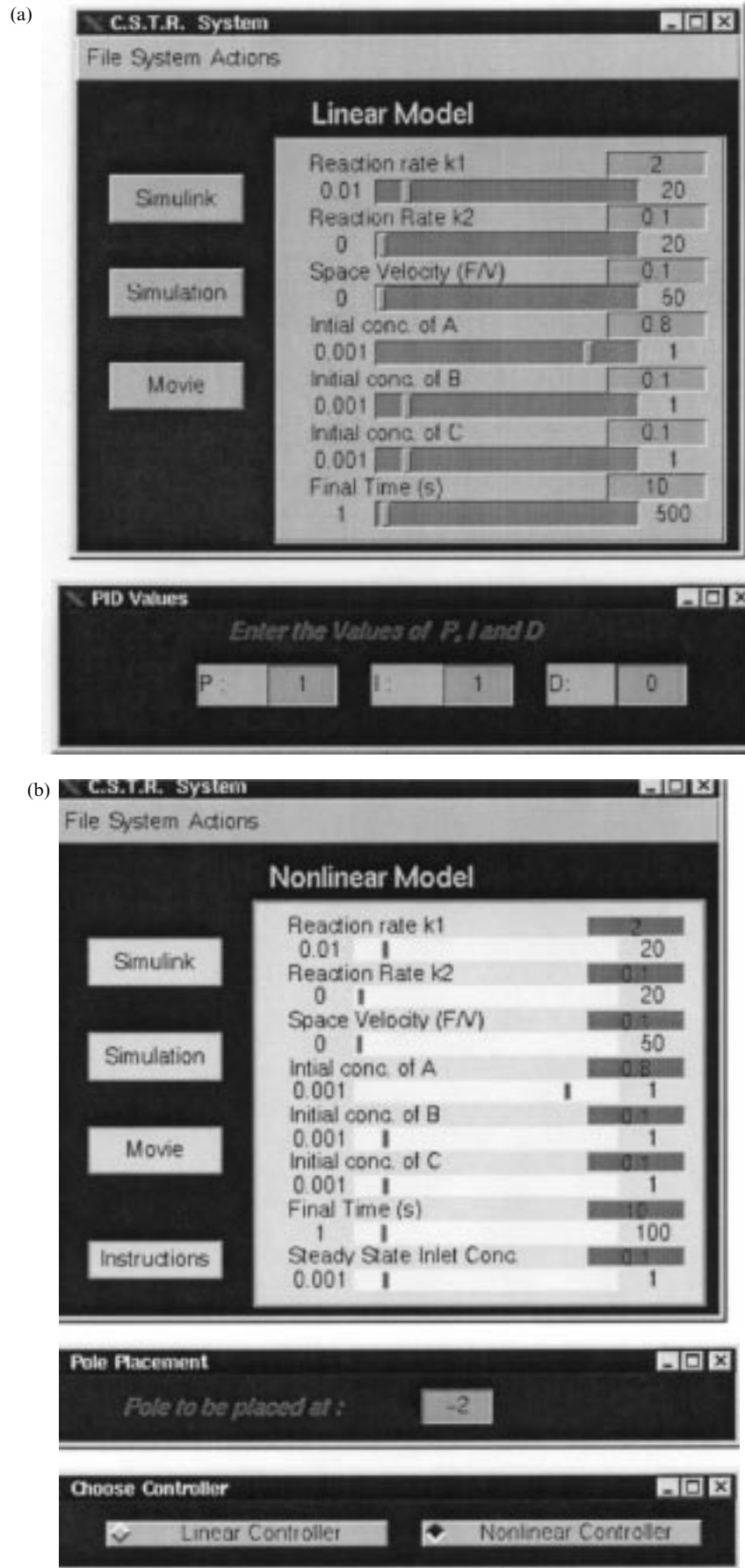


Fig. 2. (a) Linear model parameters input screen. (b) Nonlinear model parameters input screen.

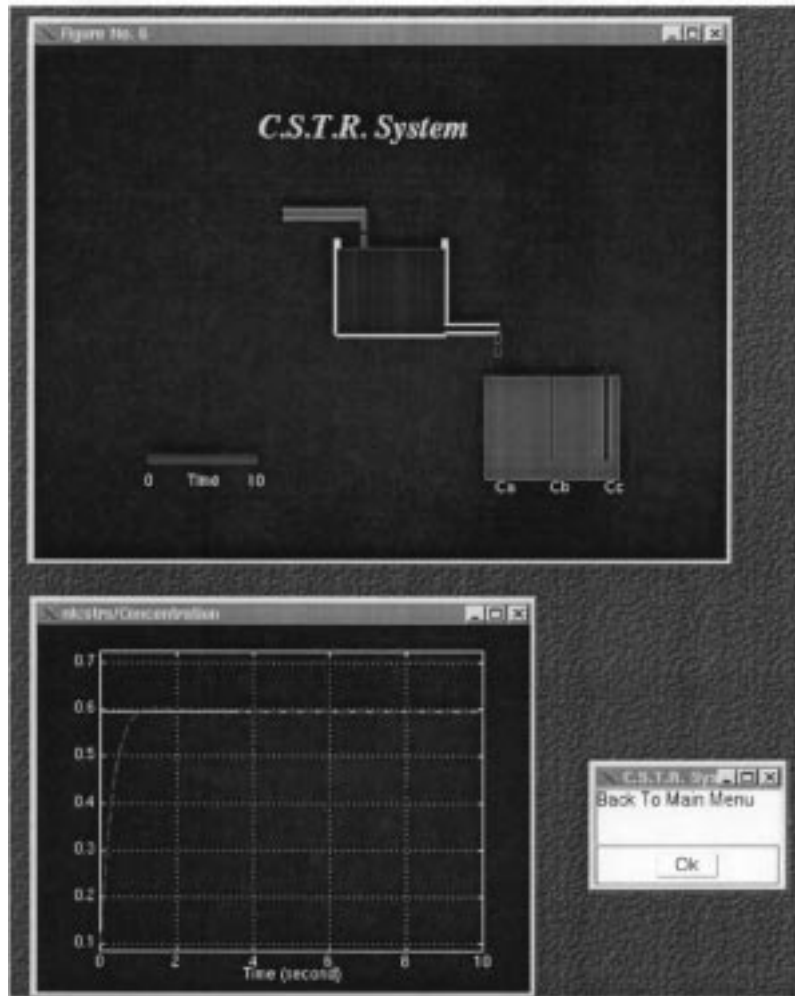


Fig. 3. Snapshot of Movie option.

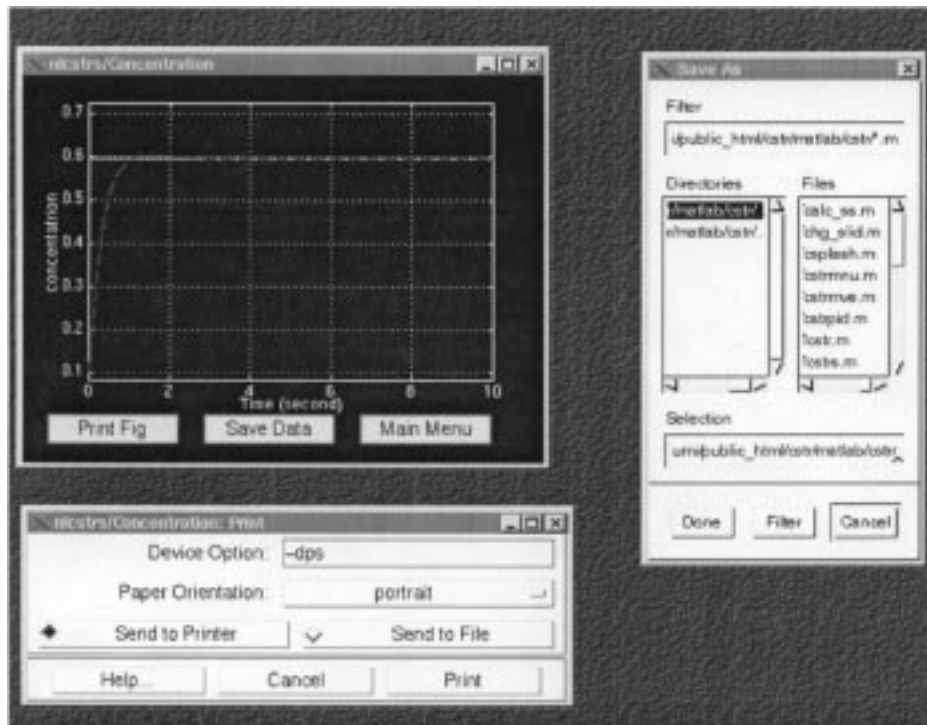


Fig. 4. Snapshot of Simulation option.

CONCLUSIONS

As a step towards the development of an Internet mediated virtual laboratory, a software module for a regulation problem in a continuous stirred tank reactor was developed. The development of such modules eliminated space, time, and cost constraints. It was found that this software

module was a useful teaching supplement to the traditional classroom lecture. Students were able to study the effect of changing various process parameters as well as controller parameters on the regulation of the output.

Acknowledgments—Financial support provided by the Learning Systems Institute at the Florida State University is gratefully acknowledged.

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Srinivas Palanki got his Ph.D in Chemical Engineering from the University of Michigan in 1992 and has been at Florida State University since then where he is currently a Professor in the Department of Chemical Engineering. His research interests lie in the areas of batch process optimization and nonlinear robust control. He has published over 35 refereed journal articles and has over 45 conference papers.

Soumitri Kolavennu got his Ph.D in Chemical Engineering from Florida State University in 1999. He is currently a senior scientist at Honeywell International Corp. His research interests lie in the areas of robust nonlinear control and the application of advanced control to the manufacturing industry.