A MOTIVATIONAL INTRODUCTION TO PROCESS CONTROL

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When teaching a course, one of the first (and sometimes one of the hardest) things to do is to motivate the students to learn the material. This is especially true of process control where students can easily get bogged down in the math, losing sight of the overall physical picture. At the University of Florida, an interactive computer game is being used as part of the introduction to process control.

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INTRODUCTORY LECTURES

Prior to playing the game, one or two introductory lectures are necessary to cover the background material. This material is commonly covered in the first chapters of process control texts,[1-7] *e.g.,* types of control strategies (feedback and feedforward), variables involved (states, disturbances, control and controlled variables), and block diagrams. A lecture on proportional-integral-derivative (PID) control covering only some basic information should then be given. This information should be presented using the CSTR system in the game as a working example. If time permits, other items that can be introduced are saturation of controllers, delays in measurements, and noise. At this point, the students are ready to play the game.

THE GAME

The game* is based on a simulation of a CSTR with a cooling jacket. In the reactor, the elementary irreversible exothermic reaction A $\rightarrow$ products is taking place. The cooling jacket is treated as a stirred tank, resulting in a saturating response with increased coolant flow rates.[8] The game has interfaces with the student using two different screens. The first is a schematic of the process, complete with a rotating stirrer and a reactor color keyed to its temperature (see Figure 1). This screen displays the process variables of interest, *e.g.,* measured temperature, coolant flow rate, and the set point. The second screen shows graphical trend lines of the same three process variables, with the current values displayed on the bottom (see Figure 2).

The student is to keep the temperature in the reactor close to a set point and at all times under 450 °C by manipulating the coolant flow rate, using either manual control or automatic PID control. If the actual reactor temperature exceeds 450 °C, the process blows up, destroying the system—with the computer showing an appropriate "BOOM!" and beeping an alarm.

The temperature measurement, however, is delayed and corrupted by noise. At several points during the game, disturbances arise with some being one-time steps and others being long-term sinusoids. The student must also deal with two set-point changes, with the second one making the set point 430°C, which is dangerously close to the critical blow-up temperature. This series of disturbances and set-point changes is purposely difficult to handle using manual control, with about half of the students blowing up before the game's completion. An automatic PI controller with Ziegler-Nichols tuning,[9] however, manages them quite well.

The game ends when the full 1200 simulated seconds have elapsed or when the critical temperature is exceeded. The students are then given the elapsed time through which they survived, the average squared error (ASE) of the temperature as a score of their performance, and a qualitative rating ranging from a best of "Control Graduate Student" to "Control Professor" and on down to a worst of "Professional Crash-Test Dummy."

* *The game program runs on IBM compatible PCs and is available at no cost on the World Wide Web at http://www.enveng.ufl.edu/process*

RESULTS

This introduction was given to an interdisciplinary process engineering class composed of undergraduate students from six engineering fields: chemical, mechanical, environmental, industrial, agricultural, and engineering science. After the introductory lectures, they played the game in a computer lab during a two-hour class period. Each student had his or her own computer on which to run the game.

Before the students started the program, the rules of the computer exercise game were established. Each student was to control the temperature manually, and the person who completed the simulation with the lowest average squared error would be declared the winner. If no one managed to finish the full simulation without blowing up, the one who survived the longest would win. They were then allowed to play.

The students met with varying success in controlling the process. Approximately fifty percent of them blew up the process, with the remaining fifty percent reaching the end. Of those who completed the game, several chose to act conservatively, maintaining the temperature well under the set point and the critical temperature. This resulted in an ASE in the range of 1000 to 2000 °C^2. The best effort resulted in an ASE of 250 °C^2.

The simulation was then run under automatic control using the default Ziegler-Nichols tuned PI controller,[6] resulting in an ASE of 120 °C^2. The controller in the game is limited to a tunable PID controller, which is sufficient for most undergraduate process control classes. During the simulation, several items were pointed out in the trend graph. Oscillations in the reactor temperature were identified and were attributed to be a result of an overly aggressive controller. Next, we discussed an effect of controller saturation where the reactor temperature was biased to under-track the set point at high temperatures. This is due to the fact that the coolant flow rate saturates at zero flow. Thus, when the controller calls for a negative coolant flow rate (in essence asking for external heating), the control valve is unable to comply and the temperature cannot increase fast enough to track the high set point.

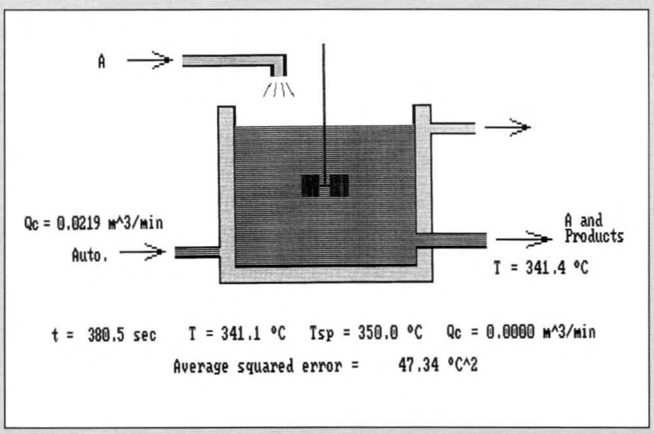

Figure 1. Process schematic screen of the process control game.

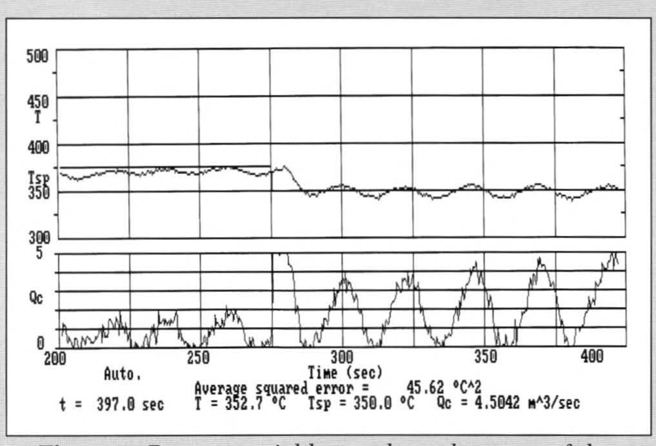

Figure 2. Process variable trend graph screen of the process control game.

The next task was to investigate the effects of the integral and derivative control. The controller, tuned to the Ziegler-Nichols PID values, resulted in a wildly fluctuating coolant flow rate due to the high noise to signal ratio in the measurement. A proportional only controller was then tried. When a large disturbance or set-point change occurred, the resulting offset was readily apparent. The students were then able to reduce the offset by increasing the gain or to eliminate it by introducing integral action.

In the final part of the class, the students were allowed to experiment with the program. Most of the students either tried to improve their ASE under manual control or attempted to find a better controller tuning. Those who tried the former improved on their initial performance, with scores dropping to a best of 143 °C^2. This activity, however, brought many comments of how difficult, tedious, and nerve wracking it was to get this level of control. Those who tried the latter task improved on the default settings and achieved an ASE of 107 °C^2, but they, too, commented on how frustrating it was to fine tune the controller and achieve the last bit of improvement. Some students experimented with other aspects of control, such as trying controller gains with the wrong sign.

After the in-class exercises, a home problem was assigned in which each student was to run the simulation under manual control and achieve a score of under 450 °C^2. A printout of the final screen had to be turned in as proof of their score. Two perceptive students, however, learned when the disturbances and set-point changes happened during the simulation and were able to enact "crystal ball" control where they could predict the onset of disturbances and act

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proactively to control them. This resulted in an ASE as low as 58 °C^2.

COMPANION PROGRAM

A companion program* based on the game can be used later in a control course to generate process models based on response curves and to tune the controller. The new simulation is essentially the same program as the game, with the measured temperature still delayed and corrupted by noise. There are, however, no pre-programmed disturbances or set-point changes, and the time is not limited to 1200 seconds. Instead, students are free to switch between automatic and manual control and to change controller tunings and open-loop coolant flow rates. Step and sinusoidal disturbances can be triggered using the keyboard. This allows them to try different tuning algorithms (*e.g.*, trial and error,[10] IMC,[11] Cohen and Coon,[12] ITAE,[13-15], and Ziegler-Nichols,[9]) and to quantify their performance in response to disturbances and set-point changes. The advantage of using the companion program is that it uses a system with which the student will already be familiar and that the program is designed for use in a pedagogical environment.

TABLE 1
Comparison of Class Evaluations with Traditional and Game-Based Introductions
(1=poor; 2=fair; 3=good; 4=very good; 5=excellent)

	Class without game software	Class with game software
Confidence in practicing feedback process control in industry	2.9	3.3
Understanding of feedback process control methodology	3.0	3.7
Understanding usefulness of feedback process control	3.5	4.2

COURSE EVALUATION

As mentioned previously, the software was first used in teaching feedback control to the process engineering class in the summer of 1996. The students in this class, as well as the students in the previous year's process engineering class (who were taught by the same instructor but without the software), were surveyed at the completion of the course. They were asked to rate their confidence in practicing feedback control in industry, their understanding of feedback control methodology, and their understanding of its usefulness. As Table 1 indicates, the 1996 students scored considerably higher than their 1995 counterparts. As the introduction of the game and the companion program were the most significant changes in the teaching of process control, the case can be made that the software boosted the students' confidence in their understanding of, and ability to practice, feedback control.

SUMMARY

The game provided an interactive and competitive exercise by which the students gained interest in process control. They saw that control is a nontrivial problem and that achieving control performance of an automatic controller using manual control is very difficult. They learned that automatic control allows processes to be safely run closer to critical levels and that tuning a controller for optimal performance is a tedious art. Their experiments also resulted in good discussion topics, including the effects of controller gains with the wrong sign and the problems of controller saturation. With this experience under their belts, the students had a clearer idea of the goals of process control and of how the material they learn in class relates to these goals.

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