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Real or Simulation: Experiences Using Computer Simulation versus Remote Operation for Process Control

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Abstract

This paper has a comparison of student reactions to having laboratory experiments conducted with simulation software and being conducted remotely through the Web. The students in a process controls course in two successive years were exposed to both simulation and remote experiments at different times during the course. We surveyed the students at the end of the course about aspects of the two methods of conducting experiments. These surveys are one of the "outcomes" of the course and are tabulated here. This paper discusses student attitudes towards the use of these two techniques as well as some changes that can be instituted to capture the best learning features of the two methods.

Introduction

Providing hands-on, or learn-by-doing, experiences for engineering students is often complicated by either a lack of equipment, technician support or both. Yet most topics in chemical engineering are best learned via a learn-by-doing approach. Computer simulations have been used in lieu of a truly hands-on experience but these are often lacking in the fullness of details that real systems provide. With the advent of high-speed Internet communications an alternative approach to providing hands-on experiences has become possible – remote operation of real equipment. Such remote operation experiences are fully learn-by-doing with nearly all the positive and negative aspects of true hands-on laboratory work.

For the past two years the process control class at Washington State University was taught using both of these approaches. Computer simulations for process identification and control were provided using Control Station® (http://ww.controlstation.com). Remote operation of actual equipment for the same purposes was provided via an Internet connection to the Resource Center for Engineering Laboratories on the Web (http://chem.engr.utc.edu) at the University of Tennessee at Chattanooga (UTC). The control class at Washington State University was divided into two groups – one to use Control Station® and the other to access the site at UTC. On subsequent assignments the groups were switched so that each group had an equal opportunity to conduct experiments via both computer simulations and remote operation. Various surveys have been employed to modify class procedures and as well as to evaluate the impact on the student's experience using these two techniques.

Procedure

The process control class at Washington State University is taught in the first semester of the senior year. The class is typical of many ChE-based control classes. The Course Objectives state that the students should be able to:

1) analyze the dynamics of process operations
2) understand the dynamic response of various operations
3) understand PID controllers for process operations based on both theoretical and empirical process characterization

The outcomes arising from the objectives outlined above are intended to partially satisfy ABET outcomes a, c, e, and k as well as the AIChE outcomes of demonstrating a working knowledge of material and energy balances applied to chemical processes, process dynamics and control, and appropriate modern experimental and computational techniques.

In the past this course was taught in a traditional manner – covering the mathematical bases of process dynamics (unsteady-state balances, Laplace transforms, etc.) first before going on to cover control and tuning. For the Fall Semester of 2003 the coverage of topics was changed with students analyzing process dynamics and tuning first, followed by coverage of the mathematical aspects and then more recent developments in control schemes. The initial homework assignments thus required that the students collect "real" data from a process. This could be accomplished by either dynamic simulation of process operations or by running experiments on real equipment and observing the dynamics.

A total of 4 assignments were given where students had to take data from either the experiment on the web site or from Control Station. The class was divided into two groups with half of the class getting their data from Control Station and the other half from the web site. For each assignment the students worked individually to collect the data and perform the requested analysis.

The heat exchanger module in Control Station and the temperature module at the web site were the only modules used for these four assignments. Because these two modules are analogous the assignments for each grouping of students were identical. We alternated the site that each student used so that every student did two experiments at the web site and two using Control Station. Table 1 shows the topics covered in each assignment as well as the student groupings assigned to each.

Table 1. Sequencing of lab assignments

Assignment Number	Description	Control Station	Web exp'ts
1	Process Dynamics Characteristics (P-only control)	Group A	Group B
2	Process Dynamics Characteristics (PI control)	Group B	Group A
3	Controller Tuning Using Direct Synthesis	Group A	Group B
4	Controller Tuning Using IMC	Group B	Group A

A typical assignment is given as the first attachment. Examples of the typical screens the students see when conducting the experiment on Control Station and at the UTC site are shown following the assignment example.

This is the second year that the process control class at WSU has been taught using both Control Station (for dynamic simulations) and the remotely operated equipment at the University of Tennessee (Chattanooga). There were 19 students enrolled in the class in 2002 and 12 in 2003. Because of the size of the class, and the fact that it is offered only once each academic year, it was not possible to split the class to try to quantify any differences in the learning between the group using Control Station and that using the remotely operated equipment. Instead students were surveyed at the end of the course to try to discern any perceived differences by the students. In 2003 we also performed a mid-course survey to try to head off any difficulties that the students might have experienced with either approach.

There were a couple of significant differences in the use of either Control Station or the UTC site in 2003 as compared with 2002. The biggest change was the scheduling of times for access to the UTC site. One of the complaints by the students in 2002 was that they could not access the UTC site just prior to when an assignment was due since another student in the class might be using the site. To avoid this students were allowed to sign-up for blocks of time during which they would have exclusive use of the UTC site. With the small number of students seeking access to the site (6) this scheduling arrangement avoided the problem of students not being able to gain access to the UTC site when they wanted. The other major change was that students were allowed to use the Design Tools module from Control Station for all data analysis, whether their data originated from Control Station or from the UTC site. The fact that their data, regardless of the source, came as a *.txt* file meant that the only substantial difference between assignments conducted using Control Station and those conducted using the UTC site was the actual generation of the data.

Results

Survey of Students at End of Course

Since all of the students in this class had the same experience, vis-à-vis the use of Control Station or the UTC site, no quantification of the differences in learning is possible. However, with two years of responses, we could compare the attitudes of these classes to the use of a simulated experiment versus use of real equipment as well as assessing the impact that the change in access to the UTC may have had on attitudes. The survey used in 2003 was identical to that used in 2002 with the exception of three additional questions meant to assess how well the changes we made addressed the access issue. The survey questions are listed in Table 2. The responses were coded with "Strongly Disagree"=1 and "Strongly Agree"=5.

Table 2. Survey Results

Item	Survey Statement	Response Avg ± SD (2003)	Response Avg ± SD (2002)
1	The instructions provided within the simulation were more understandable than those at the web-experiment site	3.6 ± 1.2	3.2 ± 0.8
2*	The web-experiment site was more readily available than was the simulation	1.0 ± 0.0	1.4 ± 0.8
3	Scheduling individual blocks of time for access to the web-experiment site allowed me adequate time to complete my assignments	3.1 ± 1.2	
4*	The simulation was easier to use than was the web-experiment site	5.0 ± 0.0	4.0 ± 1.0
5*	The web-experiment site provided a more real life experience than did the simulation	2.7 ± 0.9	3.4 ± 1.1
6	Being able to test my tuning strategies on real equipment (web-experiment site) helped me learn practical applications of control systems	2.3 ± 0.6	
7*	The graphical interface at the web-experiment site was better than that in the simulation	1.9 ± 0.9	2.8 ± 1.0
8	Using the Design Tools in Control Station for characterizing all processes was not a difficulty	4.4 ± 1.0	
9*	I feel that I learned the material better using the simulation rather than the web-experiment site	4.4 ± 0.7	3.2 ± 1.1
10*	I would prefer using the web-experiment site rather than the simulation on assignments in the future	1.1 ± 0.3	2.0 ± 1.0

The questions marked with a * are those for which a statistically significant difference (using a two-tailed t-test at the 95% confidence level) appeared between the two groups of students. These results are also shown in the following bar chart to facilitate comparison of responses from year-to-year.

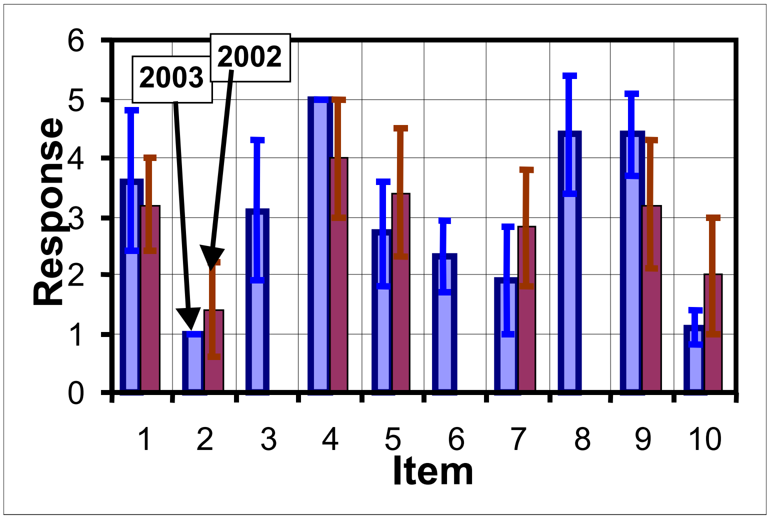

Figure 1: Responses to in-Class Survey

A number of interesting differences are observed between the results from last year and this year. One of the major complaints about using the web-based site was the lack of access. The students suggested that some type of queuing system be established to avoid the uncertainty involved when access was on a first come-first served basis. This was implemented in 2003 and the responses on question #3 indicate that the students were relatively neutral in terms of obtaining access. Yet the response to question #2 shows that this year's students felt that the web-based site was less accessible. Thus the availability issue seems to be based more on the fact that students can download Control Station directly onto their personal computers, and thus have access at any time. Web-based systems, since there will never be as many different pieces of equipment as there are students, can never match the access available via simulation systems.

This year's class also found the simulation easier to use (question #4), indicated that they felt they learned the material better using the simulation package (question #9), and showed a much stronger preference for use of the simulation package (question #10). One of the usual arguments opposing the use of simulators is that they do not provide a real life experience. Yet this year's class indicated that they felt that the simulated apparatus gave a more real-life experience, as opposed to the 2002 class that felt the web-based system gave a more real-life experience (weakly). Overall this year's class showed an exceptionally strong preference for using the simulator rather than the web-based experiments (question #10).

We also asked this year's class the same five open-ended questions that were asked last year. The questions and responses were:

1) The best feature(s) of the simulation are …
   Both groups of students gave near unanimous agreement that the best feature of the simulation was that it was fast (simulation time could be faster than real time) and always available. Other features mentioned this year were that the simulation package could be mounted in the student's own PC and that the results from the simulation were more reproducible than from the web-based apparatus. A number of students in 2003 also mentioned the variety of situations available in the simulation.
2) The best feature(s) of the web-experiment site are …
   Both groups of students were again in near unanimous agreement that the best feature of the web experiments was that it was a real experiment, even with its real-life quirks.
3) The feature(s) of the simulation that I would like to see improved are …
   The 2002 class of students wanted more access to the simulation program (home copies, for example) and more built-in instructions. There were very few comments from the 2003 class of students. The comment by one student "I like Control Station the way that it is" best sums up the sentiments expressed by this year's class.
4) The feature(s) of the web-experiment site that I would like to see improved are …
   Both groups of students wanted the real equipment experiments to run faster. The 2002 students suggested a scheduling or queuing system that was implemented in 2003. There were still suggestions that access to the remote site needed to be improved from the 2003 students (although not as many). A number of students in 2003 mentioned better reproducibility and easier access to data as features they would like to see improved.
5) Other comments.
   In 2002 many students recognized the value in the "real life" experiments but still preferred the simulation. Several suggested a smaller fraction of experiments on the web-experiment site to alleviate the bottleneck created by many students needing a number of real experiments completed. No additional comments were received from the 2003 class.

In addition to this in-class survey the 2003 class was asked to complete a survey at the UTC site. The first part of this survey covered many of the same points as the survey conducted in class. Students indicated that, on average, they operated the remote equipment 3.5 times and retrieved data or graphs from previously run remote experiments 2.8 times. The feature mentioned most commonly as something the students liked about the remote site was the fact that it involved real equipment. The feature mentioned most commonly as being the biggest disadvantage for remote operation was the fact that it was remote so that the student could not troubleshoot any problems they might have encountered. When asked to describe how operating systems remotely helped the students learn the most common response was that it showed how real systems might not function as expected, making patience a virtue. One response indicated that using Control Station was just as effective as using the remote site. When asked to describe something to improve learning from the remote site students mentioned better reproducibility, as well as was having equipment locally, rather than remotely.

The survey at the UTC site also asked 13 questions using the same 1 – 5 scale as the in-class survey. The results of this survey are on the next page.

These responses show that the 2003 students felt that the remote operation of the experiments did improve their analytical skills while being neutral on whether it helped learn effective controller operation or troubleshooting. The complete set of student responses is available on the web at http://chem.engr.utc.edu/ASEE/2004/

Table 3. Results from UTC Survey

In the items below, mark how much you think you have been helped by remote operation of laboratory equipment of access to data and graphs on the web:		Response Avg ± SD
1	General familiarity with engineering controls equipment, controller design and planning	3.2 ± 1.1
2*	Effective teamwork techniques	2.6 ± 1.3
3*	Organization of experimental testing efforts	3.0 ± 1.4
4	Preparation of work by reviewing applicable knowledge and planning all tasks by team members	3.2 ± 1.6
5*	Report writing that is brief and to the point with well documented calculations included	2.2 ± 1.1
6	Approach to effective controller operation and troubleshooting	3.0 ± 1.4
7*	Controls equipment characteristics and parts	3.6 ± 1.5
8	Engineering analysis	4.2 ± 0.4
9*	Effective data analysis	3.8 ± 1.1
10	Scale-up techniques	2.8 ± 1.1
11*	Obtaining and analyzing experimental data	4.0 ± 0.0
12*	The care needed to obtain reasonable data	4.2 ± 0.4
13	New learning	4.4 ± 0.5

* These items match up with items in the list of 13 learning objectives for laboratories developed by a colloquy sponsored by ASEE and the Sloan Foundation (Lyle Feisel and George Peterson, ASEE Annual Meeting, Montreal, 2002).

Discussion

The manner in which this class was conducted prevents any measurement of whether remote operation of real equipment or simulation of a process has any effect on the amount or quality of material learned. Based on anecdotal observation, there was no indication that either method of experimentation had a significantly greater value for the students in learning the concepts of system dynamics and control.

What is emerging, however, is a view of how students perceive these two activities. The one strong constant through both of the classes that have taken the WSU control class using both Control Station and the UTC site is the student's concern about time. Even though the amount of time required to complete an experiment was not long at the UTC site (10 minutes for warm-up and 10 minutes for actual data collection) it was considerably longer than the time required to do an analogous experiment on Control Station (2 – 3 minutes). This was a significant point for many students. In fact many of the students in the class suggested that students doing the assignments at the UTC site should receive more points on the homework because of the additional time required (even though ultimately everyone did the same number of assignments at the UTC site).

At the start of the class students were informed that in the real world most control takes place from computer screens, with little to no direct interaction with the actual equipment. Thus the computer screens presented by either Control Station or the UTC site would be typical of what they would see in practice. Students still showed a preference for actually being able to get their hands on the equipment, even if this was only downloading a program into their personal computers. It is probable that this may have been the first time that these students were faced with a situation where they could not actually get their hands on a system for troubleshooting (whether the system is real or only a simulation). Thus the strong preference shown for Control Station may be due in part to the fact that remote operation of any system is a new, and therefore unsettling, experience for the students.

In terms of deciding which method to use for a class, here are the considerations that we would highlight. If the instructor has Control Station licenses and is familiar with Control Station use, it is a powerful stand-alone tool for helping to teach the analysis and design of control systems. Web-connected experiments provide a tool that can be equally powerful. A pro for Control Station is that multiple students can do simulations simultaneously. A pro for the web-connected experiments is that multiple students can *view* the experimental results simultaneously. Inherent in any web-based system, however, is the fact that students will have to share resources (fewer devices than students) making scheduling a necessity and that any real equipment must run in real time. Simulated systems, such as Control Station, can be given to each student and can run at faster than real time. This ability to do your work whenever you want to, have it done in a shorter time, and be able to do troubleshooting yourself, rather than have to rely on another person at a remote site, are very important points for the students.

ChE 441
Process Control
Fall, 2003

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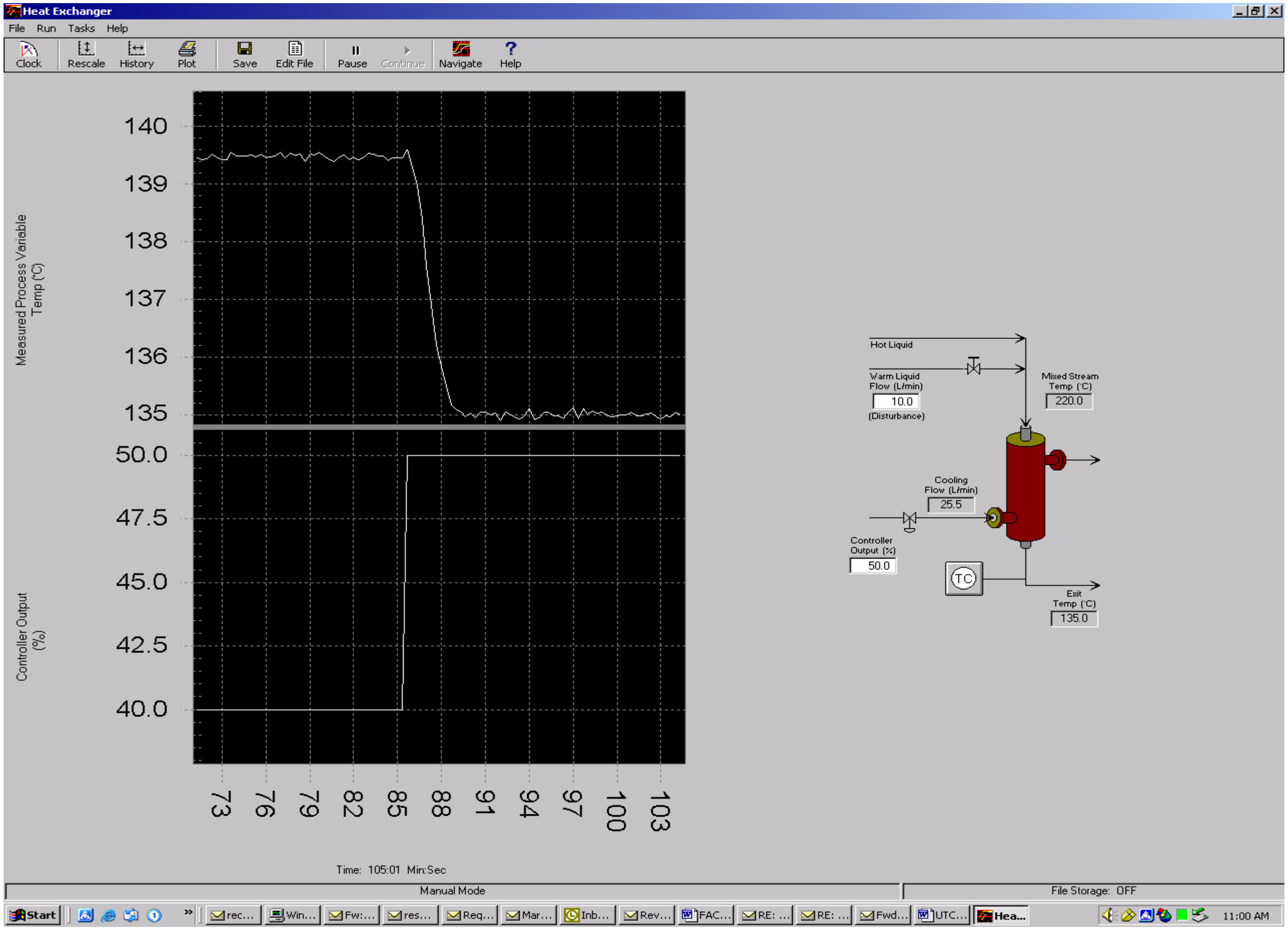
Homework Assignment #2
Due: September 10, 2003

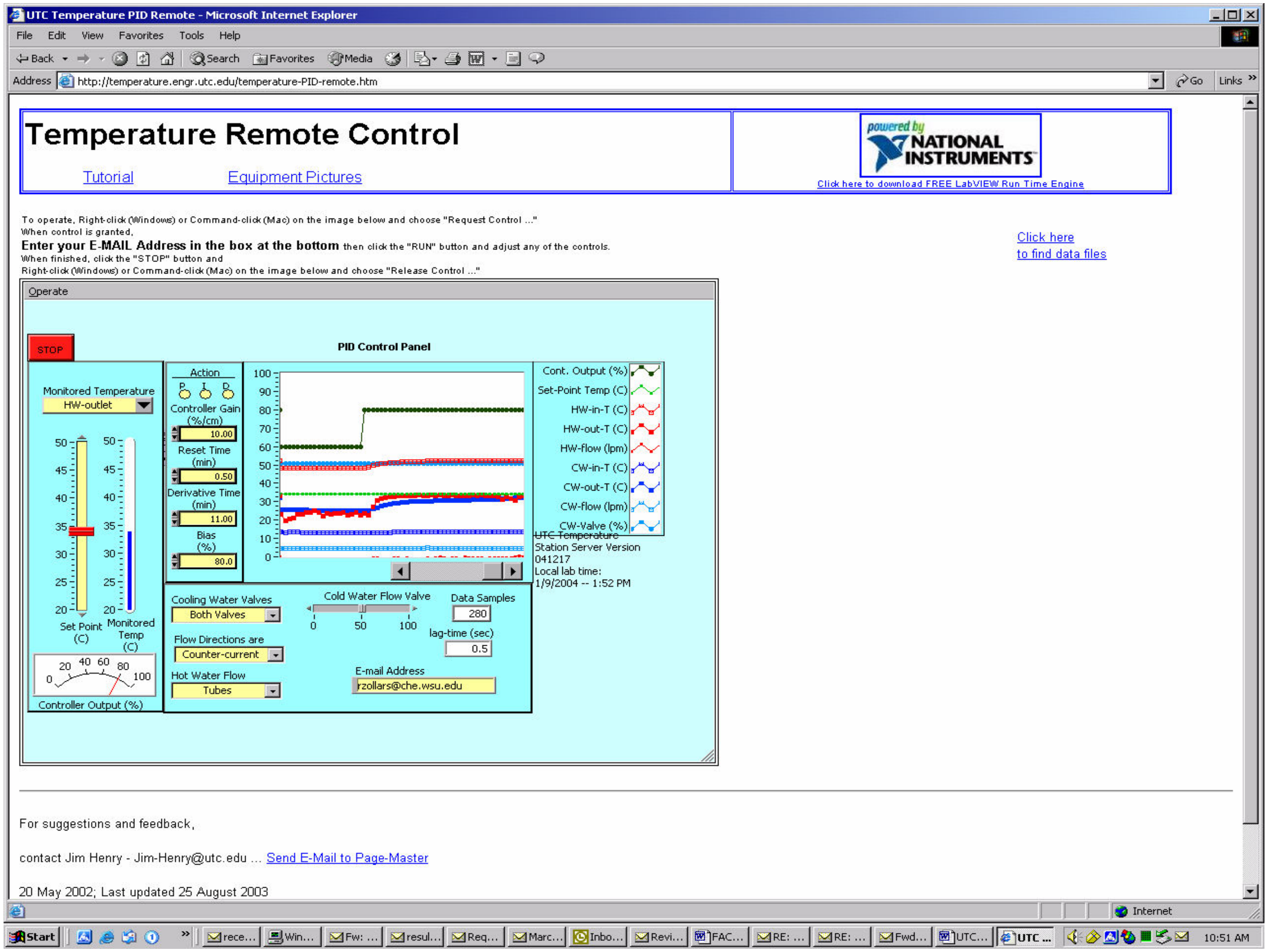
For this assignment you will be using either the heat exchanger module in Control Station® or the University of Tennessee (Chattanooga) site http://chem.engr.utc.edu/labs/wsu and the Temperature Control Experiment module. In both cases we are going to be designing a P-only controller. To do this use the following steps:

1) If you're using the UTC site make sure that you are monitoring the hot water outlet temperature, that the hot water flow is through the tubes in a countercurrent flow and that the cooling water valve setting is set at Valve-1. Use the slider to set the Cold Water Flow Valve at 50%. Add you name to the User-name block. For Control Station just use the default values.
2) Making sure that the controller is off (manual mode) adjust the controller output (bias at the UTC site) until hot exit temperature is 133°C in Control Station (40°C at UTC). Those at the UTC site should find a value between 25 and 40%.
3) Now set the controller output (bias) 5% lower than this value (e.g., if you found the bias to be 38% set a new value of 33%). Allow the system to stabilize. Now do a step test by increasing the value of the bias by 10%.
4) From the results in part 3) determine the parameters in a FOPDT model for your system.
5) Use the tuning suggestions on p. 320 of the text (for P-only control) to determine the gain for a P-only controller.
6) Switch on the controller in either Control Station or UTC and set the controller gain to the value you found in part 5). Make sure the other parameters for the controller are zero (P-only). Use a set point of 133°C for Control Station and 40°C for UTC. After the system has stabilized increase the set point by 5°C. Record the response.
7) Repeat step 6) but use a controller gain that is twice as large as you computed in step 5).
8) Repeat step 6) but use a controller gain that is four times as large as you computed in step 5).

Compare the system responses from steps 6), 7) and 8). What is the effect of the controller gain on the system response for P-only control?



Sample screen that students view from Control Station. This shows the process variables as functions of time.



Sample screen that students view from the Web experiment. This shows the process variables as functions of time.

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