Introducing Reality into Process Control Classes

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Abstract

Over the past two years the students in the process control class at Washington State University have been using the process equipment at the University of Tennessee (Chattanooga) via an Internet connection to obtain data from real processing equipment. A drawback of this arrangement is the fact that students at the remote locations cannot address equipment malfunctions on a timely basis. This year we have teamed students at the two institutions to help correct this weakness as well as providing an opportunity to have the students have experiences with communication tasks. This teaming approach proved to be partially successful. When it worked, it worked very well. When time conflicts arose, specifically near the end of the semester, the communication did not work as well for many of the students resulting in a less than desirable outcome. Plans are being formulated to correct this in the future.

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. Such an approach can, however, be frustrating for students at the remote site if the equipment malfunctions.

During the past two years the process control class at Washington State University (WSU) 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). Comments from WSU students about the desirability of being able

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to actually manipulate the equipment led to a new approach whereby students at WSU and UTC were matched so that the WSU students actually had a person at the UTC site capable of operating the system. This introduced a new aspect (communication) into what we had been trying previously while still maintaining the desirable feature of having students working with real equipment. Feedback was obtained from the students to determine the best and worst features of this approach.

Procedure – Experiment-Remote Students

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. Starting in 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 data from a process. With this data the students then can tune various types of controllers to get the response they desire from the system.

After covering a variety of tuning procedures in class, and their consequences, the students at WSU were given an assignment requiring that they obtain process data from the equipment at UTC in order to build a dynamic model. An example of the assignment sheet is attached. Rather than allowing the WSU students to conduct these experiments via the Internet, they were paired with students at UTC via a random drawing (by the instructor). The numbers of students at both sites were approximately equal (15 at WSU versus 18 at UTC) so the pairings were on a 1-to-1 basis with three UTC students not paired with a WSU student. As indicated in the assignment sheet (see Appendix) the WSU students were to give instructions on the conditions of the experiment to run to the UTC student. The UTC student then would conduct the experiment and return the data to the WSU student for analysis. To avoid having the WSU students place an unduly large burden on the UTC students, limits were placed on the number of experiments that the WSU students could request.

After obtaining data from which dynamic process models could be built the WSU students were given a second assignment. This time the assignment was to obtain a particular response from the system located at the UTC site. A sample assignment sheet (in the form of a memo) for this second portion of the project is also in the Appendix. Note that the assignment was different for each WSU student. Some were asked to tune for set point changes, some for disturbance rejection; some were asked to do this for high values of the set point, some for low values; and some were asked to obtain responses with a specific decay ratio while some were asked to obtain responses with a specified overshoot. As in the first portion of this exercise the number of experiments that the WSU student could request was limited. In addition there was a very real time deadline as finals week for the UTC students started on December 6.

Following the completion of this second portion of the exercise the WSU students were surveyed anonymously to determine their response to this procedure.

Procedure – Experiment-Resident Students

The students at UTC were enrolled in an engineering controls course, also. The course has similar objectives and uses the same textbook (Smith and Corripio) as the WSU course. The UTC students had laboratory assignments on similar laboratory equipment, also doing experiments remotely. The UTC laboratory assignments were on 4 other systems to avoid any conflict in usage with the WSU students on the temperature control system. The UTC course uses experimental assignments and analysis of experimental data more intensely and earlier than the WSU course, so the students were generally prepared for conducting the experiments for the WSU partner.

The UTC students received no course credit for conducting the experiments for the WSU partner. They were encouraged to do it as a part of this educational experiment. No complaints about it were voiced to the instructor. There were 2 cases of WSU students sending e-mail to the UTC instructor (JMH) asking about the lack of response of the UTC student partner. The system was set up to be peer-to-peer communication, so, as a matter of course, these e-mails were forwarded to the UTC student partner.

Conducting the Experiments

By in large the requests for experiments were clear and could be completed with ease. In the tuning experiments, there were a few cases where the requesting student asked for a set point that was out of the feasible operating range. The UTC students were able to help the WSU student clarify that.

The UTC students conducted 56 characterization experiments (step response). The number of experiments per student ranged from 1 to 9, averaging about 4. This number was set by the number of requests from the WSU student to the UTC student, and the number of times the UTC student ran the experiment to get good results. The step response tests were conducted over a 3 week period. The number of tests per day ranged from 1 to 12, averaging about 4.

Over a three week period, UTC students conducted 36 tuning experiments (proportional-integral tuning). The number of experiments per student ranged from 1 to 23, averaging about 5. Six WSU students conducted their experiments remotely. The number of experiments per student for the WSU students ranged from 1 to 34, averaging about 13.

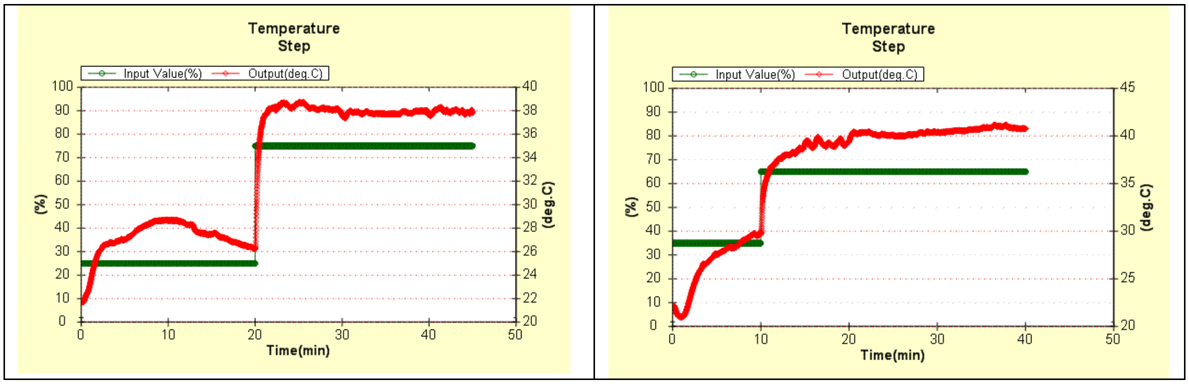
Results of the Experiments

The results of the characterization phase, for a first-order plus deadtime model, are summarized below. Although no direct instructions were given on the size of the controller output change to use, virtually all of the WSU students requested values that would put 50% of the controller output near the middle of the range they specified. The observed gain ranged from 0.213 to 0.455 ºC/% with an average value of 0.306 ºC/%. The time constant seemed to fall into one of two ranges, either about 0.3 min or over 1.0 minute. A settling time of 10 minutes is excessively long for this system. If we neglect the values greater than 1.0 minute (labeled * in the "Suspect" column) the average value for the time constant is 0.29 min. Finally the deadtime is small enough that it may be due solely to the noise in the data. The scatter observed is not unexpected given that this is real data from a real device.

Table 1: Results from Characterization Experiments

Controller Output (%)	Mean Value (%)	K_p (ºC/%)	τ (min)	t_D (min)	Suspect
30 – 65	47.5	0.223	0.246	0.084	
20 – 60	40.0	0.396	0.29	0.09	
35 – 65	50.0	0.347	2.0	--	*
35 – 65	50.0	0.330	1.79	--	*
25 – 75	50.0	0.216	0.045	0.075	
35 – 65	50.0	0.346	1.54	0.0	*
35 – 65	50.0	0.345	1.49	0.0	*
35 – 70	52.5	0.267	0.505	0.145	
50 – 65	57.5	0.246	0.345	0.03	
25 – 75	50.0	0.213	0.302	0.072	
50 – 60	55.0	0.455	0.285	0.005	
Average (omitting suspect data)	--	0.29	0.29	0.07	

Samples of the step tests run by students are shown below. The one on the left is a "good" = "useful" test. The one on the left is more demanding for proper interpretation.



Samples of the tuning tests run by students are shown below. The one on the left is a "good" test; it has fast response and no overshoot. The one on the left with its output oscillation and large controller action would likely be considered a poorly tuned controller.

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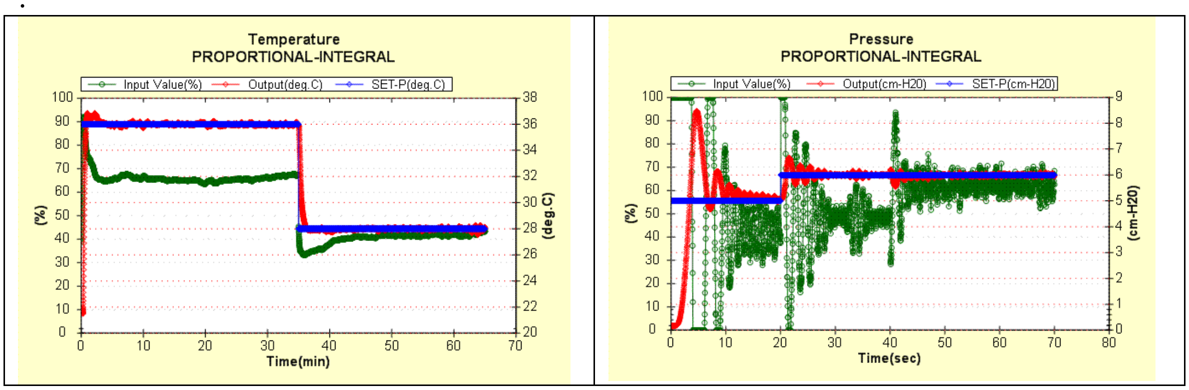


Student Responses

The WSU students were asked to respond to eight different items on a 1 – 5 scale. There were also additional items (Items 9 – 16) requiring either a numerical response or some type of comment. The results from the ranking and numerical responses are given in the table below.

Table 2. Survey Results

Item	Survey Statement	Response Avg ± SD
1	How well do you feel the student at UTC followed your instructions for the experiments designed to characterize the heat exchanger system (1 = very well, 5 = not at all)	2.5 ± 1.7
2	How responsive was the UTC student in supplying the characterization data (1 = within 24 hrs, 5 = did not reply)	2.9 ± 1.5
3	What was the quality of the characterization data you received (1 = of no use, 5 = excellent)	3.5 ± 1.2
4	How responsive was the UTC student in supplying the tuning data (1 = within 24 hrs, 5 = did not reply)	3.3 ± 1.6
5	What was the quality of the tuning data you received (1 = of no use, 5 = excellent)	2.9 ± 1.5
6	Do you feel that the amount of feedback you received from the UTC student was adequate (1 = yes, completely, 5 = no)	3.5 ± 1.7
7	How soon after receiving the characterization assignment did you make your first request for experimental data (1 = within 24 hrs, 5 = not until 24 hrs before the assignment was due)	2.4 ± 0.9
8	How soon after receiving the tuning assignment did you make your first request for experimental data (1 = within 24 hrs, 5 = not until 24 hrs before the assignment was due)	2.5 ± 0.9
9	How long did it take for you to receive the characterization data from the UTC student (hours)	43 ± 27
10	How long did it take for you to receive the tuning data from the UTC student (hours)	73 ± 69
11	After receiving the assignment, when did you make your first request for characterization data (hours)	128 ± 76
12	After receiving the assignment, when did you make your first request for tuning data (hours)	150 ± 93
13	How many characterization trials did you request?	1.7 ± 0.8
14	How many responses with characterization data did you receive?	1.3 ± 0.6
15	How many tuning trails did you request?	3.0 ± 1.3
16	How many responses with tuning data did you receive?	1.8 ± 1.5

We also asked three open-ended questions. The questions and verbatim responses were:

What were the positive aspects of this assignment?

I don't know – find something that sometimes one cannot get a system to do what we want.
Showed how to dictate directions to other employees in a real world environment
Potential to apply techniques we've learned
It allows us to work with a real system, not a simulation
Doing it on a real world setup was good
Interacting with other students at a different location
Partner in Tennessee was very quick in responding, very helpful
I could work with a new partner; test my abilities more strenuously; test my knowledge
For the first tuning assignment the guy at UTC really helps a lot, he adjusts the time used to stabilize because I gave the wrong time
I was pretty unhappy with it in general

What were the negative aspects of this assignment?

Not getting my information back
The guy at UTC didn't reply my e-mail requesting for final tuning data
No feedback on tuning #2, had to wait on UTC student
I would rather done the machine myself
Calculation of tuning parameters didn't achieve what the goal of the assignment was
Response times; my partner knew less about the apparatus than did I
We got real world data quality
I had to depend on someone else to do the data collection
No help at all form UTC
Some of the experimental data was not that great
Student didn't get back to me for 2.5 weeks. He finally did after I e-mail the teacher and sent the student several more emails

Other comments?

Couldn't set system to operate the way I wanted it to
Good idea but needs accountability at UTC
Skip the student next year, do it online, it is much easier to do it on my own
Actually we don't need to contact the guy at UTC – the data can be taken on-line
Don't do it this way again.

Discussion

The intent of this experiment was twofold – 1) to continue to have WSU students exposed to real world data in the process control class, and 2) to have both the UTC and WSU students have the experience of working with another person in directing, collecting, and communicating data. While the raw data have been summarized above, a closer analysis reveals other strong, and expected, trends.

Of the fifteen students at WSU over half requested both of the allowed two characterization runs. In many cases (over half) the second run was merely to confirm the results of the first. More than half of the WSU students made their first request for the characterization data within 24 – 48 hours of receiving the first assignment. The response from the UTC students was generally very good. There were, however, a few exceptions. In one case a WSU student made three requests for characterization data and received no responses. In a second case the initial request by the WSU student did not result in a response while the UTC student did respond to the second and third requests for characterization data. The time for the UTC students to respond to these requests varied from 4 hours up to 60 hours with an average of 43 hours. For those WSU students who did receive data during the characterization phase the feedback concerning promptness and quality of data was high. Indeed some of the UTC students went beyond what was requested to provide data for the WSU students (as shown in the next to the last response under the "positive aspects" item above) in the comments section above.

The results from the second phase of the trial (the tuning portion) were not as satisfactory. Of the 15 students requesting feedback from the UTC students only 5 received responses. Three or four others did receive a response but not until the day that the assignment was due for the WSU students. A major reason for this may be the timing of the tuning portion of the assignment. The students at WSU were given this portion of the assignment more than five weeks before it was due and one week before the characterization portion of the assignment was due. Thanksgiving happened to occur in the middle of this period, approximately two weeks before the tuning portion was due. Thus, by their own admission, about half of the WSU students waited until after Thanksgiving to make their first request for tuning data (the range of times between receiving the tuning assignment and requesting the first trails runs from 48 hours to 240 hours). The week after Thanksgiving happens to be the last week of classes at UTC, however (the next to the last week at WSU). Thus while some students received very prompt responses to their requests for tuning data (the shortest time was again 4 hours) others had response times 48 to 168 hours or received no response at all.

For the students who did receive prompt responses from their UTC counterparts most requested the full allowance of four trails (average for this group was 3.2 trials per person). They received data for every trial requested except for one, thus giving an average of 3.0 responses per person. As would be expected the evaluations given by this group of 5 students was considerably more positive than the evaluations given by the group that did not receive the responses as quickly.

Anecdotal evidence suggests that this experiment accomplished its goals, in particular the communications goal. During the characterization phase the WSU students generally received the data they requested. In a few cases what they requested was not reasonable and the UTC students changed the conditions of the experiment to give a more reasonable data set to their WSU counterpart. In every case was the WSU student able to understand the characterization data supplied to them.

For those students who had good responsiveness during the tuning phase this clear communication continued. Most of the WSU students realized that time and the number of trials allowed would put a limit on how close they could get to the desired goal. Rather than relying on rote tuning rules, such as Ziegler-Nichols tuning, nine of the fifteen WSU students modeled the system in either Matlab® or Control Station® to provide guidance on the controller parameters they requested for their tuning experiments. All five of the WSU students who received responses from their UTC counterparts used this approach and all were able to achieve the desired response in the first or second trial, although most went on to try at least once more to get even closer.

Conclusions

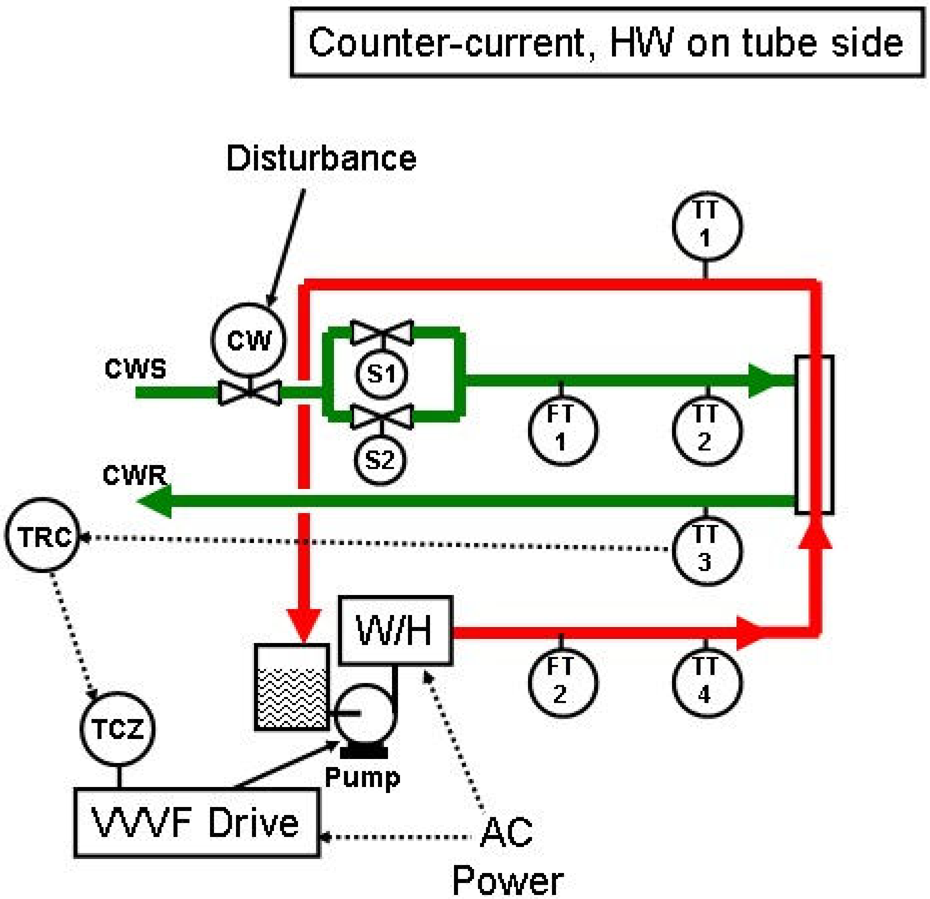
For one group of students at both WSU and UTC this proved to be a valuable learning tool. These students were able to communicate clearly with each other, obtain data that was understandable to each side, and reach a desired objective. For another group the exercise was only partially successful. During the characterization portion of the assignment they had the same experience as the group mentioned above. However, during the final, tuning portion of the assignment the communications between the students failed, thus not allowing the goals of the assignment to be completed. For a still smaller group of students the communications links were never established. The communications problems may, in part, be due to conflicts between the academic calendars at the two institutions involved. This is something that can be altered in the future to see if this problem can be corrected.

ChE 441
Process Control
Fall, 2004

Washington State University
School of Chemical Engineering and Bioengineering
Richard L. Zollars

Semester Tuning Project

Over the latter portion of the semester you are going to be asked to tune a controller to meet certain specifications for a heat exchanger that is located in Chattanooga, TN. The schematic for this system is shown below.



To assist you you will be given a contact for another engineering student at the University of Tennessee, Chattanooga. That person will conduct the tests you request according to your instructions.

The first task is to determine the dynamics for this system. Keep in mind that the system may be idle when the engineer at UTC starts so be sure to allow some time at the beginning of your run to allow the system to come to some steady-state. Then ask for a step change in the HW pump speed. Use the following script for delivering your instructions to the engineer at UTC

```
Dear [UTC student]

Will you please run a step-response experiment for me on the
Temperature control system.

I would like for the experiment to begin with a baseline input of *** %
and a step height of *** %.
I would like for the step to occur at *** minutes with a total length
of the experiment to be *** minutes.

I want the control variable to be Cold Water Outlet The flow directions
are counter-current The Hot water flow to be in the tubes.

I want the Cooling Water Valve opening to be *** % I want valves #1 and
#2 to be open 100% of the time.

Thanks,
[WSU student]
```

The baseline input referred to in the script is the HW pump speed that can be varied from 10% to 90%. The CW valve opening is a disturbance. For this portion of the project set a value for this parameter near the middle of its range (0 – 100 %). Prior experience has shown that this system responds rather rapidly with an apparent time constant of less than 1 minute.

Your analysis of the system dynamics is due by November 12 at 5:00 pm PST. Due to budget and time constraints you may only ask for a maximum of two trials to determine the parameters describing the process dynamics.

November 4, 2004

TO: «First_Name» «Last_Name»

FROM : R. Zollars

SUBJECT: Final Tuning Assignment

With the process dynamic data that you have your task is to find the tuning parameters for a PI controller that will give a «response» response for the heat exchanger system at the University of Tennessee (Chattanooga) for a step change in the «type». Your system should be operating with a set point temperature for the cold water outlet temperature of «set_point» ºC with the cooling water valve set at «valve_setting»%. After allowing the system to stabilize change the setting of the «type» to a new value of «step_size».

How well you do on this exercise will be determined by how close you come to the desired response. Missing the desired performance, both high or low, will detract from the grade on this assignment. Remember that the "plant" in Chattanooga closes for vacation on December 6. Thus all testing will have to be complete before that date. Also, due to budget limitations, you will be allowed only four trials to complete this phase of the project.

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