Using the Modern Chemical Engineering Laboratory at a Distance

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Abstract

This paper describes the technical and pedagogical aspects of conducting laboratory experiments from remote locations. 13 systems of laboratory equipment are available at UTC for students to operate remotely via the Internet. Collected data can be shared with other students via the Web. The laboratory systems are described. The advantages and disadvantages in support of the learning objectives are discussed.

Experimental setups

At UTC we have a variety of our laboratory stations available for students to operate and collect data from via the Internet. These stations are used in the Controls Systems course and the Unit Operations Laboratory Course. The stations are listed in Table 1, Remotely Operable Controls Stations[1,2,3], and Table 2, Remotely Operable Unit Operations Stations[4]. All of these are accessible from the web site http://chem.engr.utc.edu

Table 1. Remotely Operable Controls Stations.

Controls systems	
	Speed control station
	Voltage control station
	Level control station
	Pressure control station
	Flow control station
	Temperature control station

Access these experiments by clicking on "CONTROLS" on the above web page. Each of these stations is connected to a personal computer that serves as the operator's station for control and data acquisition. Whether the student-operator is sitting at the computer or is remote is irrelevant as far as the laboratory equipment is concerned. The equipment is available for conducting experiments at all hours of the day and night, every day of the week. The students do complete planning and conducting of the experiments in all these stations.

Figure 1 gives a diagram of the generic setup for these experiments. The computer contains one or more data acquisition (DAQ) cards that send signals to the laboratory equipment and receive signals from the sensors or transmitters. Students may operate the equipment while sitting at the computer station near the equipment or they may operate it remotely via a Web page interface or, in some cases, a remote program that communicates directly between the remote and the laboratory computers.

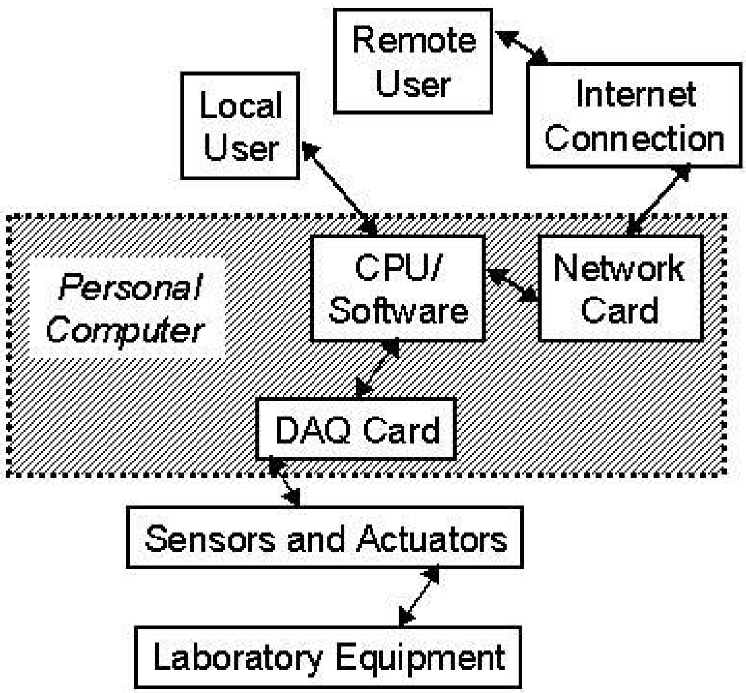

Figure 1. General connection of Laboratory equipment with computer

For all these stations, students-users can run a variety of experiments. There is a set of "system identification" experiments and a set of "controller design" experiments. The system identification experiments include (1) a constant input value (useful for developing the steady state operating curve), (2) a step function input (for obtaining reaction curve, step response data), (3) sine function input (for obtaining frequency response behavior and Bode plots), (4) ramp function input, (5) pulse function input, (6) a design-your-own function input and, recently added, (7) a relay-feedback or clamped proportional feedback function[5]. The controller design experiments are for testing the tuning of PID controllers.

For the two simplest stations, Speed Control and Voltage Control, there is one actuator, a variable-voltage, variable-frequency drive for the 3-phase motor that is the actuated device in the equipment. This motor drive receives an analog signal from the DAQ board upon computer command. For each of these, there is one sensor (speed sensor or voltage sensor) that sends a signal to the DAQ board. Figure 2 is a diagram of this setup. These two "stations" are actually the same system; the user chooses whether the computer collects speed or voltage data.

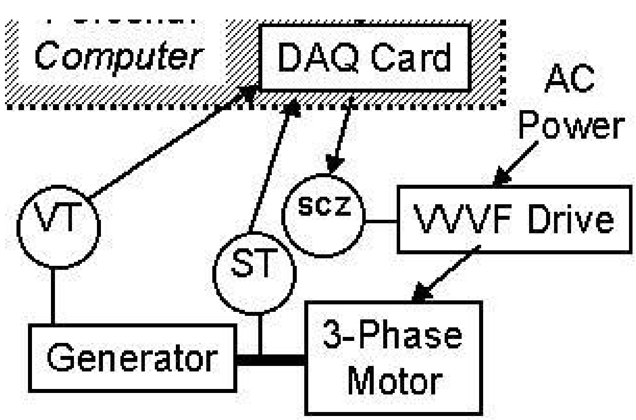

Figure 2. Details of Speed and Voltage Control Stations

These two systems are essentially, single input, single output systems. The "input" to each system is the manipulated variable ranging from 0-100% of full motor output. The "output" of each system is the controlled variable. For speed it is RPM in the range 0-1800 RPM; for voltage is it DC Volts in the range 0-140 Volts.

For the Level Control station also has one actuator, a pulse-width modulated DC power supply that drives the pump in the equipment. This power supply receives an analog signal from the DAQ board upon computer command. In the controlled-level tank, there is a level transmitter composed of a hydrostatic pressure sensor at the bottom of the tank. Figure 3 is a diagram of this setup. There are actually two totally independent tanks that can used on this station; one has an inside diameter of about 2 inches, the other has an inside diameter of about 6 inches.

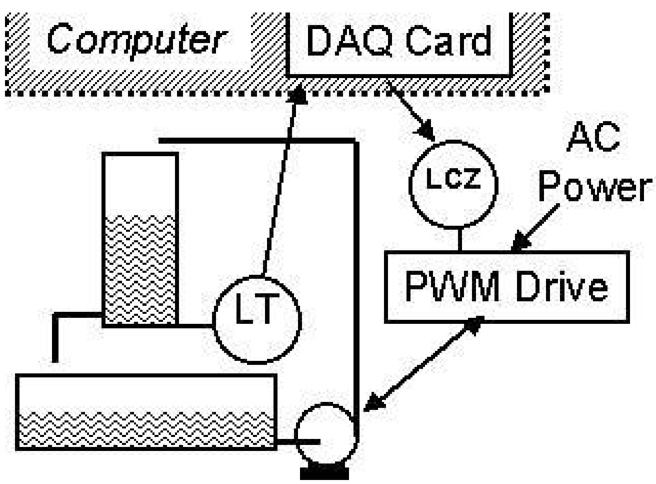

Figure 3. Details of Level Control Station

The level system is also essentially, a single input, single output system. The "input" to the system is the manipulated variable ranging from 0-100% of full pump output. The "output" of the system is the controlled variable, water level in the range of 0-70 cm.

For the Flow Control and Pressure Control stations also each have one actuator, a variable-voltage, variable-frequency drive for the 3-phase motor that is the actuated device in the equipment. This power supply receives an analog signal from the DAQ board upon computer command. In the flow control system, there is a micro-Motion Coriolos force flow transmitter in one arm of the flow system. Figure 4 is a diagram of the Flow Control system setup. In the pressure control system, there is a pressure transmitter at the blower outlet. Figure 5 is a diagram of the Pressure Control system setup.

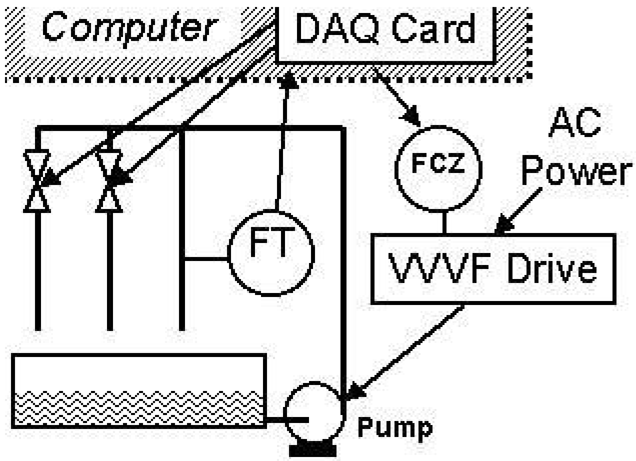

Figure 4. Details of Flow Control Station

The flow system is also essentially, a single input, single output system. The "input" to the system is the manipulated variable ranging from 0-100% of full pump output. The "output" of the system is the controlled variable, water level in the range of 0-70 cm. This system has two "disturbances" that can be activated at the will of the operator. They are two motor-operated valves that provide a bypass of the water out of the line that contains the flow transmitter.

The pressure system is also essentially, a single input, single output system. The "input" to the system is the manipulated variable ranging from 0-100% of full blower output. The "output" of the system is the controlled variable, air pressure in the range of 0-7 cm-H_2O. This system has two "disturbances" that can be activated at the will of the operator. They are two motor-operated dampers that provide a blockage out of two of the three lines that exhaust the airflow.

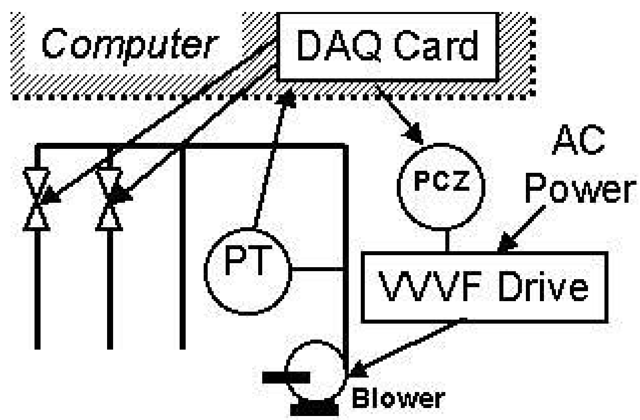

Figure 5. Details of Pressure Control Station

For the Temperature Control station there are two actuators: one is a variable-voltage, variable-frequency drive for the 3-phase motor that drives a pump in the hot water loop. The other is a variable control valve in the cold water supply line. These actuators receive analog signal from the DAQ board upon computer command. The temperature is read at 4 points and the flow is measured in the two loops, hot water flow and cold water flow. Figure 6 is a diagram of the Temperature Control system setup.

The temperature system is a multi-input, multi-output system. The "inputs" to the system are the manipulated variable ranging from 0-100% of full pump output and 0-100% of the CWS valve opening. The "outputs" of the system are the controlled variables, and are the temperatures of the hot water outlet and the cold water outlet. This system has a "disturbance" that can be activated at the will of the operator. It is a pair of solenoid valves that provide a restriction in the cold water flow line. In the diagram, the signal lines from each of the transmitter to the DAQ card are omitted for clarity and the disturbance valves are not shown.

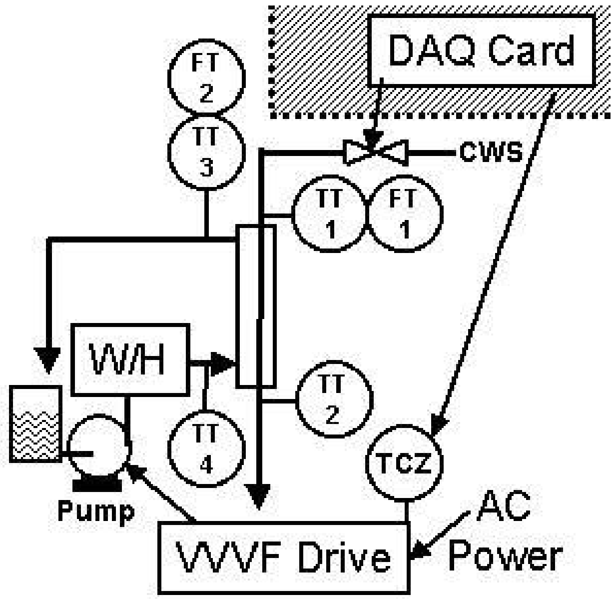

Figure 6. Details of Temperature Control Station

The heart of the temperature control system is a shell-and-tube heat exchanger. The system is valved so that the flow can be either counter-current or co-current and the hot water can be either on the shell side or the tube side. This allows for a variety of interesting control situations to be examined.

For the "Unit Operations" stations, they are mainly "manually" controlled. Essentially, we have our students operate them in manual mode to observe the equipment's typical operating characteristics. Access these experiments by clicking on "PROCESS DYNAMICS" on the above-mentioned web page.

Table 2. Remotely Operable Unit Operations Stations.

Unit operations	
	Heat exchanger station
	Flow through porous media
	Packed column absorption
	Distillation
	Batch dryer
	Pressure swing absorption
	Gas-fired water heater

The Heat Exchanger station is the same station that is used for Temperature Control, just described. For unit operations, we have the students do the heat balances and calculate the heat transfer coefficients.

The Flow through Porous Media station consists of water being pumped through one of four pipes filled with small glass beads. The pipes are of two different lengths, 4 feet and 8 feet, and two different diameters, 1 inch and 2 inches. The students can specify a pump rate (similar to the Level system described above) and observe the pressure drop across the porous media path.

The Packed Column absorption station (Figure 7) is a packed column stripper. It is 4 inches diameter and 4 feet tall, packed with 1/4-inch glass rings. At this time, we only have students study the flow dynamics of the system. The liquid is a (recycled) loop of water. The gas side is compressed air. Under computer control, again either locally or remotely, the water flow rate or airflow rate can be varied. The computer receives signals for the flow rates and the pressure drop across the column. Under remote operation, we restrict the flow so that flooding does not occur. When it is operated locally, the students do have the capacity to operate under flooding conditions.

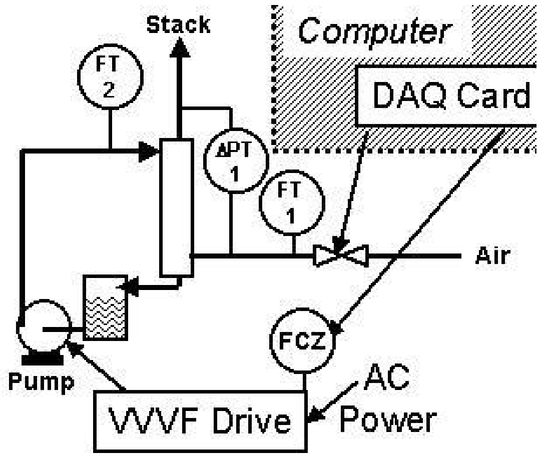

Figure 7. Details of the Packed Column Absorption Station

The Distillation Column (Figure 8) is a 12-tray, bubble-cap column. The tray diameter is about 4 inches. The student is able to control the heat to the reboiler, the reflux ratio and the feed flow rate. The computer receives signals for the flows, temperatures and the pressure drop across the column. Under remote operation, we restrict the conditions so that flooding does not occur. When it is operated locally, the students do have the capacity to operate under flooding conditions.

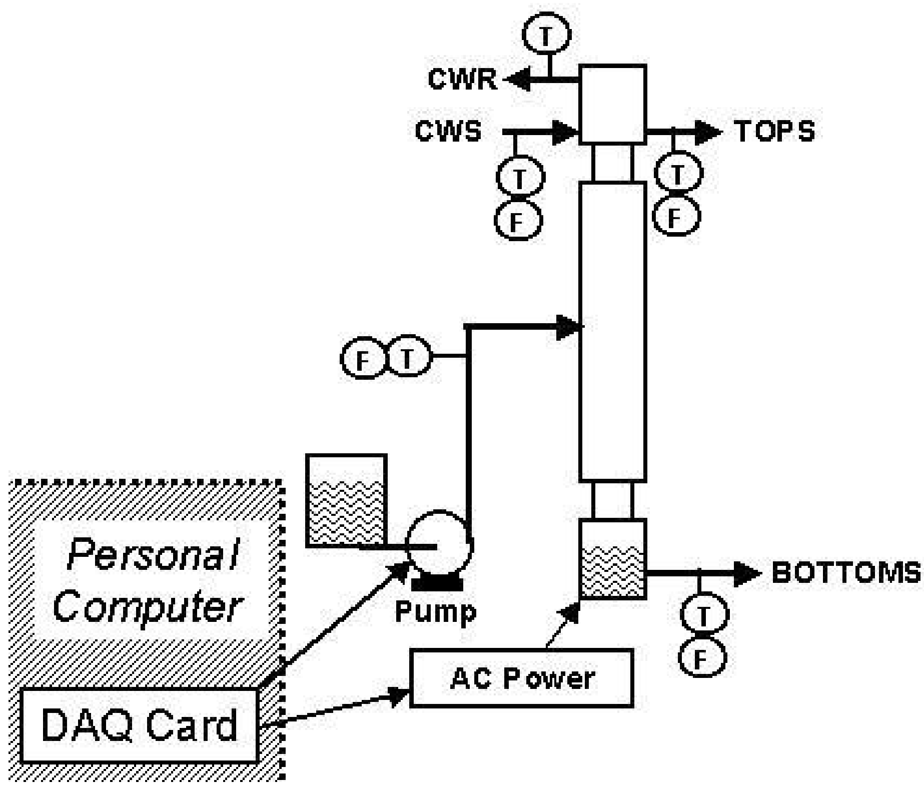

Figure 8. Details of the Distillation Station

The Batch Dryer station consists of eight trays of sand in a large oven with a variable temperature control. Each tray is suspended on a load cell that senses the weight of the tray. The drying experiment may take as long as 10 to 20 hours. The students can begin the experiment in the laboratory and monitor the progress of the experiment remotely. We have plans for the entire experiment to be operable remotely in the near future.

The Pressure Swing Adsorption experiment consists of a commercial home oxygen concentrator that has been extensively instrumented for flow, temperature and concentration. Remote operation of the unit is possible. The students can change the pressure swing cycle time and observe the impact on oxygen production rate and concentration.

The Gas Fired Water Heater is a domestic gas water heater that is extensively instrumented for flows and temperatures of the water and air and flue gas and the flue gas composition. The water flow rate is controllable by the student. The students can study combustion and heat transfer in this system.

For safety reasons, all these systems are equipped with safety shut-downs and other safety monitors. The safety shut-down will turn off any equipment if the controlling computer fails.

On-line capabilities

Each of the experimental stations is on-line 24 hours a day, 7 days a week. The students can run the experiments at any time from any location on the Internet. The experiment is queued according to a privilege ranking that students are given. Otherwise, the experiments are run first come, first serve.

The students design their experiments according to the objectives of the experiment and submit, via the Internet, a request for the experiment to be run. The equipment is operated by networked computers according to the students' specified parameters. The computers collect the data and present the results to the students via the Web. The data is also saved on the laboratory Web server for later retrieval[6,7].

Team communication

Teamwork and collaborative learning are important in our lab courses. When a student runs an experiment, he or she can notify teammates who can observe and/or download the results at another location[8].

We have developed a Web "front-end' to facilitate this team communication. This is a support system for team interaction associated with laboratory assignments. Each student has a personalized Web-Lab site that presents links to all experiments run by the team.

Typical assignments

We have found it effective, where possible, to start students out with simpler experiments and then have them proceed to experiments in which they are observing more complex phenomena.

For example, in Controls, we have all students in the first week to take data and construct a steady-state operating curve for their system. In fact, steady-state performance curves are good starting points for nearly all of the experiments we mention here.

Desired outcomes for laboratory courses

We have the following as desired learning outcomes for our laboratories:

- learn by doing
- guided discovery
- demonstrate by experiment the phenomena developed in lecture or textbook
- design of experiments
- collection of data
- analysis of data
- presentation of data and results

All of these are possible with the experiment being run remotely. We are in the process of collecting data that measures the meeting of these outcomes for our students[9,10].

Conclusions

Modern chemical engineering laboratories can have equipment control and data acquisition by computers that are controllable via the Internet. All of the desired learning outcomes for students can achieved by such remotely controlled equipment. A teamwork support system integrated with Internet operated laboratories can be effective in helping students learn.

Acknowledgement

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