Modern Engineering Laboratories at a Distance*

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This paper describes the technical aspects of conducting laboratory experiments from remote locations. Sixteen laboratory systems 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 described in the paper could be used by engineering and engineering technology programs in lieu of or to supplement existing laboratory curriculum content.

UTC EXPERIMENTAL SETUPS

THE College of Engineering and Computer Science at UTC has made a variety of its laboratory stations available for students to operate and collect data from via the Internet. These stations are used in the Controls Systems course, the Unit Operations Laboratory course and the Senior Mechanical Engineering Laboratory course. The stations are listed in Table 1 as Mechanical Engineering Stations [1–7], Table 2 as Controls Stations [8–10], and Table 3 as Chemical Engineering Stations [11–15]. All of these experimental systems are accessible from the website http://chem.engr.utc.edu/Labs/Other.htm.

Access to these experiments is obtained by clicking on 'Mechanical Engineering' 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 perform the complete planning and conducting of the experiments in all the stations described here.

Figure 1 presents a schematic of the generic setup for these experiments. The computer contains one or more data acquisition (DAQ) cards that (1) send signals to the laboratory equipment to control system parameters and (2) receive signals from the sensors or transmitters for parameters being measured. 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 laboratory computers.

For all laboratory systems at UTC, LabVIEW software and DAQ boards by National Instruments are used for data acquisition, control and communication. Some of the systems are 'real time', controlled remotely by either web page plug-ins using LabVIEW 6.1's Web serving facility or by separate LabVIEW remote client programs, or 'batch' runs with experiment specifications that are submitted by users through a Microsoft Internet Information Server.

Kinematics of motions station

The kinematics of motion station comprises a single-cylinder gasoline engine with its cylinder head removed. A 3-phase motor connected to a variable-voltage, variable-frequency drive, externally drives the crank. The motor drive receives an analog signal from the DAQ board upon computer command. An LVDT position sensor for both piston and valve sends an analog signal to the DAQ board. Figure 2 presents a schematic of this system.

The user specifies what rotational speed is desired for the crank and whether the piston or valve motion is to be observed. The equipment then runs the motor at that speed and collects position and time data from the appropriate sensor. LabVIEW then generates the first and second derivative of the position data and makes graphs of position vs time, speed vs time and acceleration vs time for either the valve or piston motion. The piston motion is studied with the crank and connecting rod lengths being determined using the experimental data and TK Solver or Maple. A detail study of the experimental valve motion enables the student to

Table 1. Remotely operable mechanical engineering stations

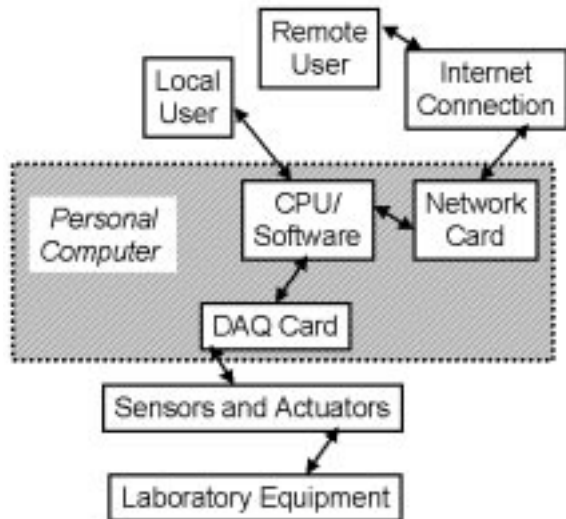| |
| --- |
| 1. Kinematics of Motion |
| 2. Linear Vibrations |
| 3. Heat Exchanger |

Fig. 1. General connection of laboratory equipment with computer: CPU is the central processing unit of the computer; DAQ is the data acquisition plug-in card in the computer.

determine the type of cam profile (parabolic, cycloidal, or harmonic) that is being used in the engine.

Linear vibrations station

The linear vibrations station consists of an upgraded Sanderson linear vibrations system. It has a mass, spring and damper with a variable-speed motor drive. Electronic sensors were added to measure position, velocity, and acceleration of the vibrating mass and displacement position of the base excitation while the variable-speed drive is computer control via a pulse-width modulated DC power supply. Figure 3 presents a schematic of the vibrations system.

The user specifies what speed to run the drive motor, ranging from 1 to 5 Hz, and the desired length of the experiment, ranging from about 1 to 10 s. Upon receiving the request, the computer runs the experiment and returns a web page to
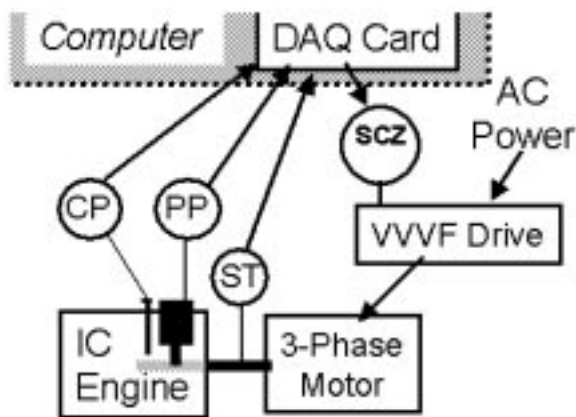

Fig. 2. Details of kinematics of motion station: CP is the cam position sensor' PP is the piston position sensor; ST is a speed transmitter (tachometer); SCZ is the speed control drive; VVVF Drive is the variable voltage, variable frequency motor drive.
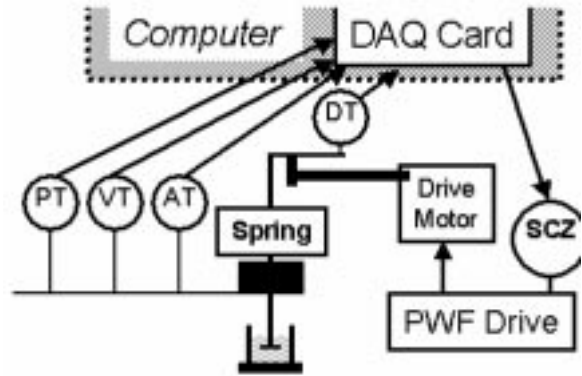

Fig. 3. Details of linear vibrations station: PT is the position transmitter for the mass; VT is the velocity transmitter for the mass; AT is the acceleration transmitter for the mass; DT is the drive position transmitter for the base, or driven element; PWF is the pulse width modulator.

the user with two graphs: a graph of the excitation (base drive) position and the response (mass) position versus time and a phase plot, or Lissajous graph, of the response (mass) position versus the excitation (base drive) position.

Heat exchanger station

The heat exchanger station consists of a shell-and-tube heat exchanger. For this station there are two variables available for user control: one is a variable-voltage, variable-frequency drive for the 3-phase motor that drives a pump in the hot water loop and the other is a variable flow control valve in the cold water supply line. The water passes through a thermostatically controlled electric hot water heater before going to the heat exchanger. These actuators receive analog signals from the DAQ board upon computer command. The temperature is measured at four points (inlet and outlet temperature for both hot and cold flows of
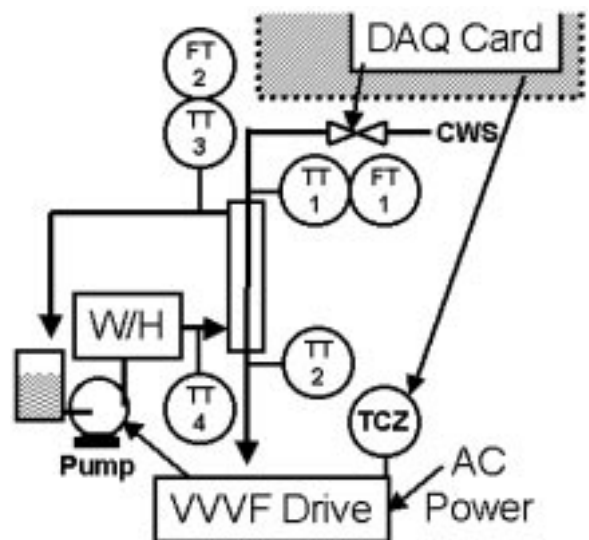

Fig. 4. Details of heat exchanger station. FT are the flow transmitters; TT are the temperature transmitters; TCZ is the temperature control drive; W/H is the electric water heater; CWS is the cold water supply.

Table 2. Remotely operable control stations

4. Speed Control Station
5. Voltage Control Station
6. Level Control Station
7. Pressure Control Station
8. Flow Control Station
9. Temperature Control Station

the heat exchanger), and the water flow rate is measured for both hot and cold water flows. Figure 4 presents a schematic of the heat exchanger station. In the cold water loop, there are two solenoid valves in parallel that can be opened and closed on command. These serve to simulate 'disturbances' to the system during normal operations. In Fig. 4 the signal output lines from each of the transmitters to the DAQ card are omitted for clarity and the disturbance valves are not shown.

Temperature control system

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 operating situations to be examined. The temperature system inputs are the hot water loop flow variable ranging from 0–100% of full pump output and 0–100% of the cold water loop flow CWS valve opening.

Control stations

For each control station, students-user 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:

- constant input value (useful for developing the steady state operating curve),
- step function input (for obtaining reaction curve, step response data),
- sine function input (for obtaining frequency response behavior and bode plots),
- ramp function input,
- pulse function input,
- design-your-own function input and,
- relay feedback or clamped proportional feedback function [17] (recently added).

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. This motor drive receives an analog output signal from the DAQ board upon computer command. For each of these systems, there is one sensor (speed sensor or voltage sensor) that sends a signal to the DAQ board. Figure 5 presents a schematic of the system. These two 'stations' are actually the same system; the user chooses whether the computer collects speed or voltage data.
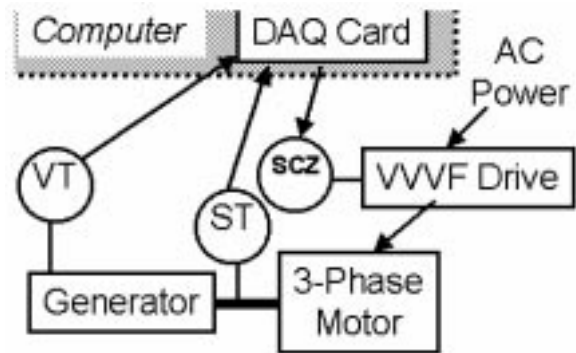

Fig. 5. Details of speed and voltage control stations: ST is the speed transmitter; VT is the voltage transmitter.

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, it is DC V in the range 0–140 V.

The level control station also has one actuator, a pulse-width modulated DC power supply that drives the pump in the system. 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 6 presents a schematic of the system. Two totally independent tanks can be used at this station; one has an inside diameter of about 2 inches, the other has an inside diameter of about 6 inches.

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. This power supply receives an analog signal
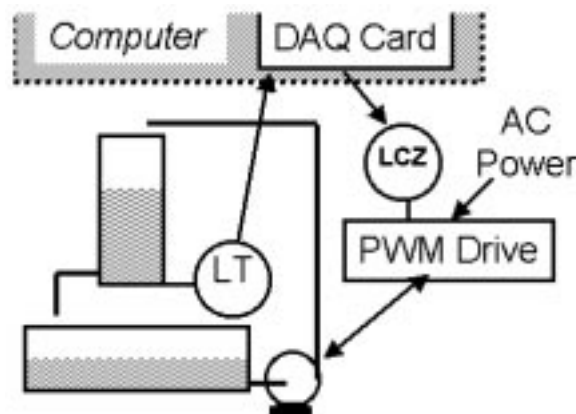

Fig. 6. Details of level control station: LT is the level transmitter; LCZ is the level control drive.
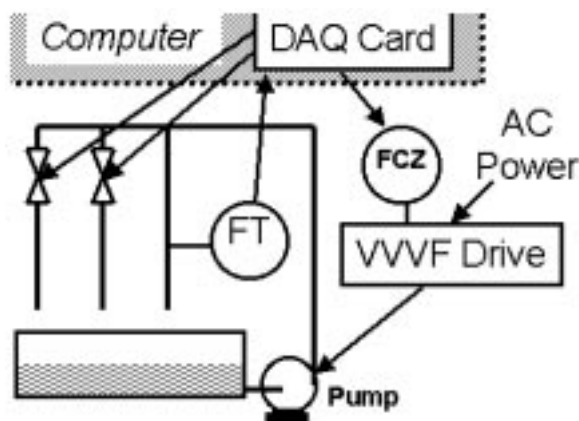
Fig. 7. Details of flow control station: FT is the flow transmitter; FCZ is the flow control drive.

from the DAQ board upon computer command. In the flow control station a MicroMotion coriolis flow rate sensor is located in one branch of the flow system. Figure 7 presents a schematic of the flow control station. In the pressure control station, a pressure transmitter is located at the blower outlet. Figure 8 presents a schematic of the pressure 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 discretion of the operator by opening two motor-operated valves that bypass water out of the line that contains the flow transmitter.

The pressure station 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 of H_2O. This system has two 'disturbances' that can be activated at the discretion of the operator by closing two motor-operated dampers that provide a blockage out of two of the three lines that exhaust the airflow.
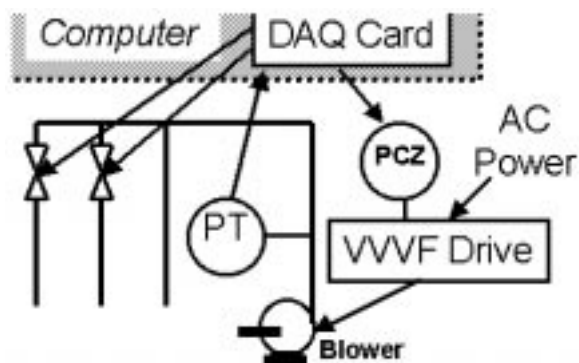

Fig. 8. Details of pressure control station: PT is the pressure transmitter; FCZ is the pressure control drive.

Table 3. Remotely operable chemical engineering stations

10. Packed Column Absorption
11. Distillation
12. Heat Exchanger Station
13. Flow Through Porous Media
14. Batch Dryer
15. Pressure Swing Absorption
16. Gas-Fired Water Heater

The temperature control station is the same hardware mentioned above as the heat exchanger station. 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. Since 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, a variety of interesting control situations to be examined.

For the chemical engineering stations, they are mainly 'manually' controlled. Essentially, our students operate them in manual mode to observe the equipment's typical operating characteristics. Access to these experiments is obtained by clicking on 'Chemical Engineering' on the above-mentioned web page.

Packed column absorption station

The packed column absorption station as represented in Fig. 9 is a packed column stripper. It is 4 inches diameter and 4 feet tall, packed with ¼-inch glass rings. At this time, UTC students only 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, the flow is restricted so that flooding does not occur. When it is operated locally, the students do have the capacity to operate under flooding conditions.

Distillation column

The distillation column (Figure 10) 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, flow conditions are restricted so that flooding does not occur. When it is operated locally, the students do have the capacity to operate under flooding conditions.

Other stations

The heat exchanger station is the same station that is used for mechanical engineering station Number 3 described earlier. For unit operations,
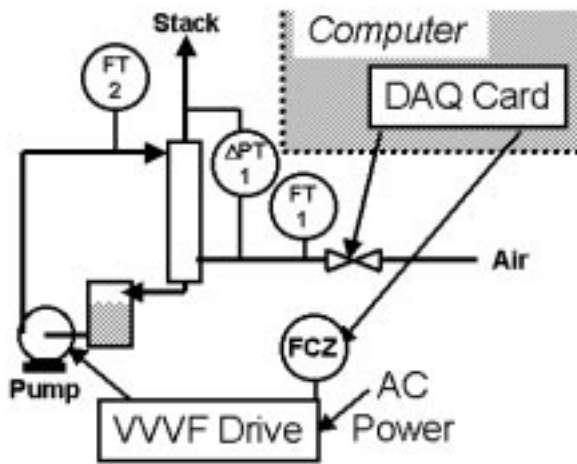
Fig. 9. Details of the packed column absorption station: ΔPT is the delta-pressure transmitter.

the students conduct heat balances and calculate the heat transfer coefficients.

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. Plans exist to remotely operate the entire experiment in the near future.

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
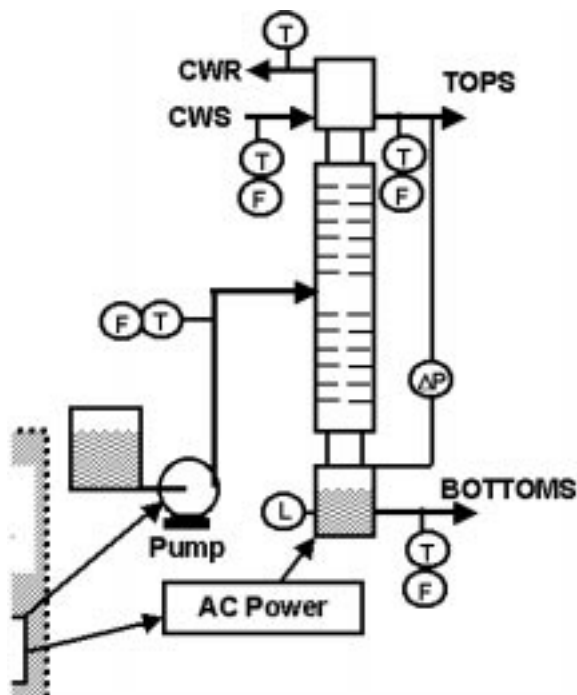

Fig. 10. Details of the distillation station: ΔP is the delta-pressure transmitter; T, L and F are the temperature, level and flow transmitters.

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 pressure swing adsorption station 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 student can change the pressure swing cycle time and observe the impact on oxygen production rate and concentration.

The gas-fired water heater station is a domestic gas water heater that is extensively instrumented for flows and temperatures of the water, combustion air and flue gas and measuring the flue gas composition. The water flow rate is controllable by the student. The students can study the effect of combustion parameters and heat transfer in this system.

For safety reasons, all these systems are equipped with safety shutdowns and other safety monitors. The safety shutdown will turn off all 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 on a first come, first served basis.

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. Networked computers according to the students' specified parameters operate the equipment. 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 [15, 17].

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.

A Web 'front-end' has been developed 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 observe more complex phenomena. For example, in Controls, all students in the first week 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 mentioned 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 outcomes are possible with the experiment being run remotely. Student-faculty responses are being collected to provide outcomes assessment for our students [15].

CONCLUSIONS

Modern 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 be achieved by using remotely controlled equipment. A teamwork-supported system integrated with Internet-operated laboratories can be effective in helping students learn.

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