Remote Laboratory Operation: Web Technology Successes

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Abstract

National Aeronautics and Space Administration (NASA) has awarded Fort Valley State University (FVSU) a three-year project to develop an undergraduate minor program in computer based measurement and instrumentation. The primary objective of this program is to enhance the existing mathematics, engineering technology, and computer science programs at FVSU. The implementation of the minor program will help students gain a solid foundation in computer science, engineering, physics, and modern experimental sciences through hands-on laboratory-based approaches with state-of-the-art technologies.

The Department of Mathematics and Computer Science of FVSU is currently developing a modern computerized instrumentation lab to support the curriculum of the minor program. The lab is being equipped with various experimental setups that could be used to perform scientific experiments for lab science courses offered at FVSU. These setups will be fully controlled, monitored and operated by computer systems using virtual instrumentation technology. They also feature on-line capabilities that allow users to operate them remotely through the Internet.

Equipment has recently installed in this lab that can be operated remotely via the Internet. The equipment consists of (1) a motor-generator set with a variable speed motor and a variable resistive load and (2) a variable-speed water pump, flow and level system. This paper discusses the way these are used in classes for teaching programming and data-acquisition. The paper presents typical assignments and a survey of student satisfaction and student complaints.

Computer-Based Measurement and Instrumentation

The lab development is based on the assumption that students in computer science and engineering technology need experiences with computers that are broader than standard "computer literacy" and programming. Computers are now quite powerfully used for data acquisition and equipment control. Students in this program will gain experience in computer use with these technologies.

Computers are being used to make physical measurements with sensors that send signals to data-acquisition boards and the experimental data is read in the "virtual instrument" paradigm. That is, the computer and its software perform the same functions that conventional instruments do, and more. "Conventional instruments" means voltmeters, ammeters, thermometers, torque indicators, tachometers, level sight-gauges, rotameters and similar instruments as conventionally used in technical instrumentation. The "and more" indicates that in addition to taking the readings, the software can collect and record the data, present the data as graphs and publish results to the World Wide Web. More about this is in the next section of this paper.

The computer-based measurements in our systems are made using LabVIEW software and data acquisition boards from National Instruments. More about this is in the section following the next in this paper.

The sensor instrumentation comprises the list mentioned above. In detail, they are

- Voltmeters: The data acquisition boards are inherently DC voltage measuring devices. They have 16 channels of analog voltage inputs. They are typically configured to read in the range of 0-10 volts DC. To read higher DC voltages, resistive voltage dividers are used. To measure lower voltages, the input channels can have on-board gain applied. Using this, they can read voltages down into the millivolt range. To measure AC voltages, signal conditioners are used. Typically, these are in the "6B" series from Analog Devices. These are available with (virtually) any specified range of AC input voltage and produce a proportional DC voltage in the range of 0-5 volts DC to be read by the data acquisition board. Then the software converts it to the real experimental value.

- Ammeters: For measuring DC current, a small resistor is put in the circuit and then (with the data acquisition board) the voltage across the resistor is measured; Ohm's Law then gives the current. In one example, the "small resistor" is actually a length of copper wire. The resistance is on the order of 50 milli-ohms. Thus the voltage for, say 10 amps is about 500 milli-volts. For this low voltage, a signal conditioner is used which produces a proportional DC voltage in the range of 0-5 volts DC to be read by the data acquisition board. This accomplishes the reading of the low voltage with less noise than by using a high gain in the data acquisition board amplifier. For measuring AC current, current sensors from American Aerospace Controls are used. They come in a range of sizes. They convert the AC current into a DC voltage in the range of 0-10 volts DC to be read by the data acquisition board.

- Thermometers: For measuring temperatures, integrated circuit temperature devices are used. These are known as "LM-35" devices from National Semiconductor. They are much lower cost than either thermocouples or resistance temperature devices (RTDs) and are simpler than thermisters. These devices are about the size of a No. 2 pencil eraser. They require a source of DC voltage (about 12 volts) to operate. They produce a DC output voltage that is the temperature divided by 100. The data acquisition board can read this voltage and the software converts it to the real observed temperature. They are available in either Celsius or Fahrenheit models.

- Torque indicators: For measuring torque, a strain-gauge-based torque sensor from Futek Sensors is being used. As with many strain gauges, it has strain gauges in a Wheatstone Bridge, so when an input voltage is applied across two terminal of the bridge, an output voltage appears across the other two terminals that is proportional to the torque. This output voltage is on the order of millivolts, so, again, for this low voltage, a signal conditioner is used which produces a proportional DC voltage in the range of 0-5 volts DC to be read by the data acquisition board. Using the calibration constant of the torque sensor, the software then converts it to the real observed torque.

- Tachometers: For measuring rotational speed, a reflected-light photo sensor is being used which has a square-wave voltage output with a frequency proportional to the frequency at which reflective spots on the motor shaft pass the sensor. This output voltage is sent to a signal conditioner which produces a proportional DC voltage in the range of 0-5 volts DC to be read by the data acquisition board. Using the number of reflective spots per revolution and the calibration constant of the signal conditioner, the software then converts it to the real observed rotational speed.

- Level sight-gauges: For measuring level of liquid in a tank, an amplified piezoresistive pressure sensor from Sensym is being used. They require a source of DC voltage (about 12 volts) to operate. They produce a DC output voltage that is proportional to the pressure at the bottom of the tank. Using Bernoulli's Equation for hydrostatics, the pressure is proportional to the height of the liquid above the sensor. So the data acquisition board can read the voltage and the software converts it to the real observed liquid level.

- Rotameters: For measuring flow rate of liquid, a paddle-wheel flowmeter from Davis Instruments is being used. This instrument has magnets embedded in a paddle-wheel that rotates at a rate proportional to the liquid velocity in the sensor. There is a coil near the paddle-wheel. The voltage induced by the magnets passing near the coils is of a frequency and magnitude that is proportional to the rotational speed of the paddle-wheel. This small AC voltage is send to a signal conditioner that produces a proportional DC voltage in the range of 0-5 volts DC to be read by the data acquisition board. The software converts it to the real observed liquid flow rate. Quite surprisingly, this paddle-wheel flowmeter has a different calibration in turbulent flow regime than it does in the laminar flow regime.

Experimental Setups

Three experimental setups at Fort Valley are described here.

The motor-generator station is a table-top unit that has a three-phase AC motor driving a DC generator. The motor is driven by a variable-voltage, variable frequency AC inverter. The inverter receives an analog output signal form the computer to control the speed of the motor. The coupling between the motor and generator has 4 strips of reflective tape that is sensed by the reflective photosensor. The photosensor sends a pulse train to the frequency signal conditioner that converts the frequency to a voltage that is fed to the analog input signal. The voltage generated by the DC generator is sent directly to an analog input channel. A reaction torque sensor measures the torque on the generator. The torque sensor output is sent to a low-voltage signal conditioner and then to an analog input channel. The generator's DC output current can go to any of eight filaments on light bulbs. The choice of filaments is made by the computer user and digital outlet lines control relays to choose the appropriate filaments. The DC current to the filaments is measured by Ohm's law, as mentioned above. The Ohmic voltage is sent to another analog input channel. Five temperature sensors monitor the temperature at various places on the unit: the ambient air, the AC inverter, the motor case, the generator case and the air heated by the lighted filaments. (A small fan blows ambient air across the bulbs.)

Figure 1. Motor Generator station

The pump-flow-level system consists of a DC motor-driven centrifugal pump that pumps water from a reservoir to a gravity-drained receiving tank. The receiving tank drains back to the reservoir for a closed-loop water circuit. The pump speed is controlled by pulse-width modulated digital line out of the computer. The flow rate of the pumped water is measured by a paddle-wheel flow meter. The paddle-wheel sends a pulse train to the frequency signal conditioner that converts the frequency to a voltage that is fed to the analog input signal. The height of liquid in the tank is measured by the hydrostatic pressure with a pressure sensor at the bottom of the receiving tank. The liquid efflux line can either be siphoned off or free flow out of the tank. A solenoid valve controlled by the computer makes that choice.

Figure 2. Variable speed pump-flow-level station

The heat transfer station is composed of a pencil soldering iron. The iron is in contact with a long rod along which several thermocouples have been attached. The heat transfer rods are made of various metals. Conduction and natural and/or forced convection heat transfer are taking place. The thermocouples are connected to signal conditioners that then send a voltage to the analog input channels.

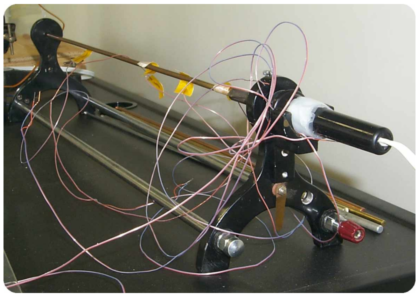

Figure 3. Heat Transfer Station

On-Line Capabilities

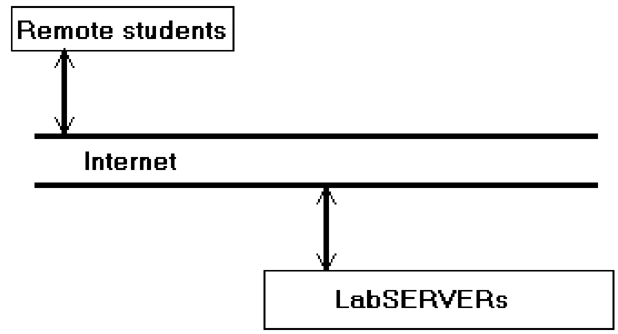

Figure 4. Connection of Remote Users to the Laboratory

Two of our experimental setups at Fort Valley are entirely controllable from the Web. The systems are the motor-generator station and the variable-speed pump-flow-level station. The LabVIEW experiment-controlling program on the laboratory computer is connected to the Web. Another computer connected on the Web can run a LabVIEW program that communicates with the laboratory computer. This remote computer thus can operate the equipment just as easily as a user sitting in the lab. The equipment is operated from the remote site and the data is returned to the hard drive disk on the remote computer. A diagram of this connection is shown in Figure 4. The web site for the experimental systems at the University of Tennessee at Chattanooga can be accessed at http://chem.engr.utc.edu.The web site for the experimental systems at Fort Valley State University can be accessed at http://www.mcs.fvsu.edu/facility/facilities.html.

Typical Assignments

First, the students are introduced to operation of each of these stations. The students collect data over a number of different operating conditions and plot curves of the results. The software is programmed to collect the data and create a text file of the data versus elapsed time. The students use Microsoft Excel to read the data files and plot their results.

The students submit a report that includes their results and analysis and a description of the principles that can be observed in their data and graphs.

The students to make physical measurement, where possible, using conventional measuring instruments to make spot verifications of the computer-based measurements.

The students to modify the software in various specified, as well as open-ended ways, to become familiar with programming for computer-based measurements.

Student Responses

Students who have used the Web-capable laboratories have been surveyed about their experiences. Their responses include

- We can pick the time to meet to run the labs instead of being required to be here for a set class time
- The ability to perform experiments from remote locations
- You can run experiments during class time or at 3AM as well as turn in your reports at any time over the web
- I liked the freedom of the lab
- It worked out well being able to work at different times
- This was a new experience. Especially running the experiments on the Web, and sending the assignments by e-mail
- Web access learning is very important these days, when a lot of information is available and e-mail is taking the place of traditional phone calling and letter writing.

Conclusions

Computer based measurement and instrumentation has been found to be a very effective way to give a solid foundation in state-of-the-art technologies. Extending of this capability to remote access on the Web has added to the students' learning opportunities.

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References to Suppliers

American Aerospace for AC current sensors
http://www.a-a-c.com/0.htm

Analog Devices for signal conditioners
http://www.analogdevices.com/

Davis Instruments for paddle-wheels
http://www.davisontheweb.com/

Digikey for temperature measuring integrated circuits
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Futek for torque sensors
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National Instruments, for LabVIEW programming and data acquisition boards
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Omron for photosensors
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Sensym for pressure sensors
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