Adding Automatic Control to the Senior Laboratory Experience

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Introduction and Background

Our program has 2 semesters of senior laboratory requiring a total of 4 credits. We also had a second semester junior level required data acquisitions and control laboratory for 2 credits. The Department decided to drop the junior course and integrate data acquisition and control into the senior lab courses. One objective was to reduce the credit load. Another objective was to introduce larger data acquisition and control experiments into the senior laboratory experience and modernize our manual laboratory equipment. The senior lab is now 3 sessions of 3 hours per week.

The senior laboratory courses contains a standard set of experiments without automatic control including; flow rates, cooling tower, friction factor, valve characteristics, heat transfer, distillation, evaporation, reaction and others. The second semester junior course included data acquisition and control experiments including reactions heating and cooling, filtration, liquid level in a tank and some simple data acquisition and control introductory experiments. These included introduction to LabVIEW software and analog and digital signals,

Our new laboratory concepts include using software and a PC with the appropriate auxiliaries for data acquisition and control similar to the data acquisition and control laboratory and provide a closer connection to our senior control course.

These concepts include electric and pneumatic signals, analog and digital signals, PI controllers, gain, negative and positive transfer functions, and sensors. New laboratory equipment introduced includes analog control valves, digital solenoid valves, analog pressure transducers, analog thermocouples with signal enhancement, analog flow meters, both analog and digital solid state relays, and other equipment. We also are using the necessary auxiliary hardware to take data and control devices, as well as LabVIEW.

Laboratory Description: Objectives and ABET

There are five objectives of the data acquisition and control part of the senior laboratory.. Each of these are related to the ABET outcomes indicated by the letter following each outcome.

The student will learn

1. to develop the laboratory skills needed for data acquisition and control. (b)

2. to integrate data acquisition and control with the use of the microcomputer. (b), (k)

3. to reinforce the concepts in the chemical engineering control course. (e)

4. to be able to report experimental results in an engineering format. (g)

5. to be able to work in teams. (d)

The ABET program outcomes related to the above objectives are:
Engineering programs must demonstrate that their graduates have:
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(g) an ability to communicate effectively
an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The five major themes of the course include digital and analog input, digital and analog output signals, and timing. These signals are acquired from sensors and transducers. Software for data acquisition and control is used. DAQ control devices and solid state relays and proportional power controllers are needed to allow for power to supply the devices being controlled.

Students generally work in teams of three or four. Laboratory reports are required for every assignment. Grades are allocated for participation, 30%, laboratory reports, 60%, and team effort, 10%. Maintaining and renewing technology is a real challenge.

The course helps develop the skills and knowledge needed to acquire data and control processes using the personal computer. The important ingredients for meeting this goal include; personal computers, data acquisition boards, appropriate software, sensors and transducers, and control devices.

Major laboratory safety procedures involve the use of electricity. An important tool for this course is the multi-meter to measure DC electric signals. The Five Basic Elements of Data Acquisition and Control with a Personal Computer (PC) involves verifying the analog in, analog out, digital in and digital out values.

A personal computer as part of the data acquisition or control loop must be able to acquire analog or digital input signals and output analog or digital signals. Many of the real signals are analog. Digital to analog converters, D/A, for output and analog to digital converter, A/D for input are used to interface with the digital world of the personal computer and are located on the DAQ's.

Control methods include both digital and analog devices. For example a solenoid valve is controlled with a digital signal while a proportional valve is controlled with an analog signal. Digital control is the simpler of the two control methods since only an on/off signal need to be received by the device. For a solenoid valve a 5 volt signal might turn the valve on while a zero volt signal would turn the valve off. An electrical heater is another example of a device that can work with either digital or analog control. The heater can either be on or off, digital control, or we can vary the current to the heater, proportional control. To send these signal we simply need an electrical switch. A simple electrical switch available commercially is called solid state relays. Other electrical switches are available.

The students also master the following skill list:
1. CONNECT A PIECE OF EQUIPMENT TO A MICROCOMPUTER
2. CONNECT THE DEVICES NEEDED FOR CONTROL OF THE EQUIPMENT
3. USE A COMMERCIAL SOFTWARE PROGRAM FOR DATA ACQUISTION AND CONTROL
4. COLLECT DATA FROM AN EXPERIMENT OR SYSTEM
5. PREPARE GRAPHS AND TABLES OF THE DATA
6. ANALYZE THE DATA COLLECTED BY THE MICROCOMPUTER

Experiments

We are focusing on six experiments to be included in the senior lab that include data acquisition and control. These are outlined below in this section. The first senior experiments to be modified include a standard laboratory friction factor system with different diameter pipes.. We used to use manometers for pressure measurement and now are using analog pressure transducers. We used to control the flow by hand and now use proportional control valves. We used to choose the pipe to measure the friction factor with hand valves and now are using digital signal controlled solenoid valves. Data acquisition includes pressure drop and flow. The design for this project included selection of the proper devices for the correct range of variables. Our second example was a laboratory cooling tower used to cool hot water with ambient air. Similar concepts were introduced for this experiment. Our intentions are to automate other senior laboratory experiments. Each of these labs lasts 4-6 3 hour sessions (up to two weeks). To help prepare the students for these experiments we may give mini-lectures or have discussions with the teams.

In addition to the below listed experiments the students may spend time on a large distillation column or a dual stage evaporator or other experiments.

Control Valves

The lab has two electric control valves as stand alone experiments. Both use water as the transport fluid. Both use a USB data acquisition board (DAQ). The setup is shown in Figure 1. One is a solenoid valve in which a digital signal from LabVIEW controls whether the valve is off or on. The valve is power by a simple AC circuit and is controlled by a DC signal of either zero or 5 volts. The control is simple with five volts for on or zero volts for off. The digital signal leaves the computer and completes the circuit of a solid state relay (SSR).

The other valve is a proportional control valve. This valve takes a variable analog signal and opens in proportion to the signal. The valve is also powered by a simple AC circuit. The analog signal leaves the computer and enters a proportional power controller (PPC). The PPC then sends a signal to the valve proportional to the required flow rate. This operation needs to be calibrated. LabVIEW is used to control this valve with the required changes in flow rate.

Friction Factor

The friction factor is a standard method used in many flow laboratories. Included in the setup are bends, valves, flow measurement devices and four different size pipe. The old experiment measures pressure drop with a manometer. We replaced the manometer with relatively accurate differential pressure transducers. The flow rate was controlled with standard globe valves. We a proportional control valve into the experiment. The data acquisition using the pressure transducers is an analog signal that enters the computer and the valve is controlled by an analog signal leaving the computer. Both the valve and the transducers use a DAQ USB device in between the signal and the computer. Figure 2 shows the friction factor experiment.

Cooling Tower

The cooling tower is a relatively standard one use in other chemical engineering laboratories. The tower is set up with a vertical set of thermocouples. These analog signals enter a USB DAQ board and are stored in the computer using LabVIEW. The flow rate of water moving down the cooling tower uses a proportional control valve to vary the flow rate. We would eventually like to control the rising air stream and are searching for some mechanical device that can control the blower through a motion control. Figure 3 shows the cooling tower.

Reaction Calorimeter

The reaction calorimeter is a relatively complex piece of equipment from Mettler-Toledo. It has its own proprietary control complex software. It will measure the heat of reaction with high accuracy. The software controls the flow of oil for cooling or heating in the jacket of the reactor. It also provides for a set of calibration experiments. Mixing is included and the RPM of the mixer is also controlled. Figure 3 shows the reaction calorimeter components.

Filtration with Backflush

This experiment provides for filtration of a dirty stream. As the pressure across the filter builds up the flow entering the filter is halted and a backflush occurs. The pressure drop across the filter is measured with a differential pressure transducer providing an analog signal to the computer. The setup includes four solenoid valves including two for the inlet and outlet of the feed stream and two for the control of the backflush stream. The solenoid valves (on/off) are controlled with digital signals. The software used to control this experiment is LabVIEW.

Three Tanks in Series
We attempt to integrate the control part of the senior laboratory course with the material of the automatic control course given in the second semester of the junior year. One theoretical set of calculations in the control course involve three tanks in series. It is relatively straightforward to use material balances to model the time dependent behavior of this system. Pressure transducers will help to control the level in the middle tank. An upset in the system can be introduced in the middle tank by using a pump to pump fluid out of the tank. A proportional control valve can control the flow rate into the first tank.

Conclusions
So far the implementation of these data acquisition is proceeding smoothly. These experiments are not all required but the students do a subset of the total of all the experiments in the lab. Other experiments include distillation in a 20 foot high distillation column with condenser and reboiler. Also we have a relatively complex two stage evaporation process. Other experiments include heat transfer and mixing. This last set of experiments is not controlled automatically but is very hands on. The students have the opportunity to have an interesting mix of controlled experiments and hands on experiments.

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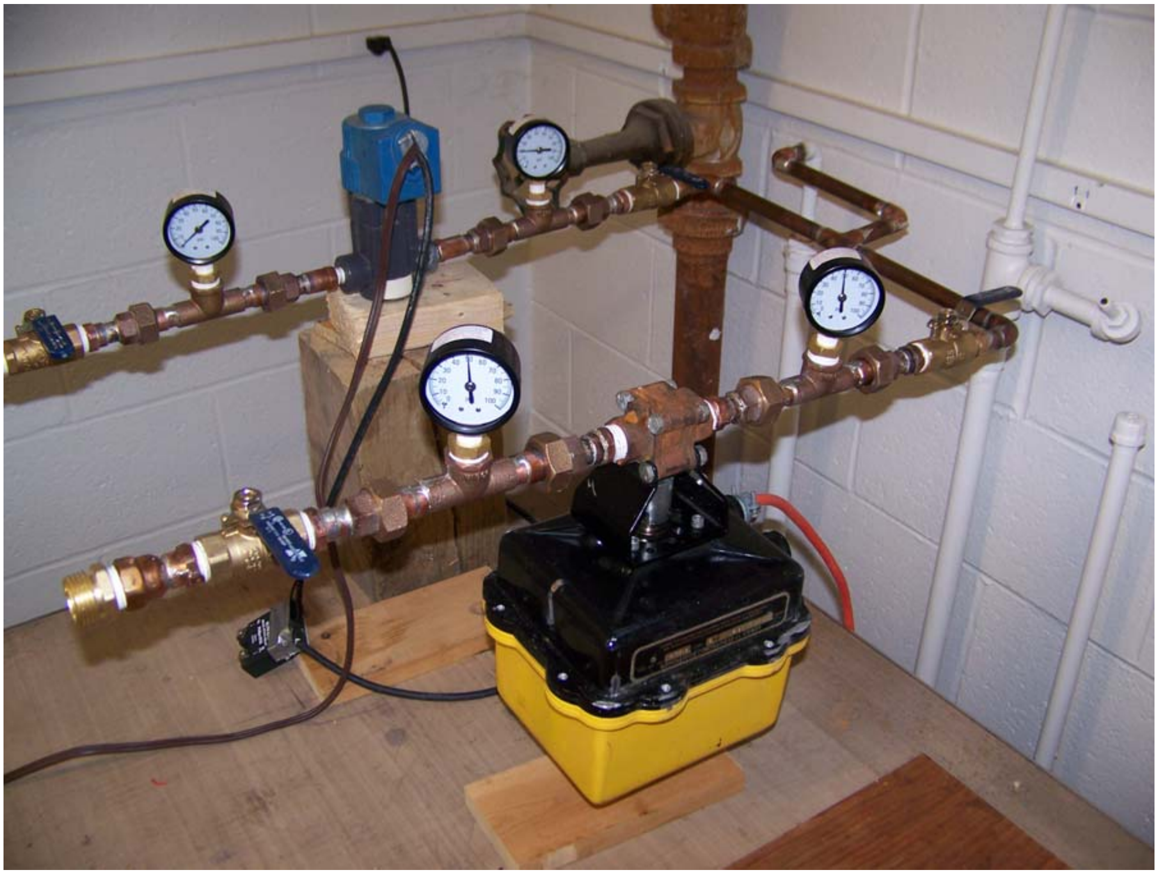

Figure 1. Flow Control Valves

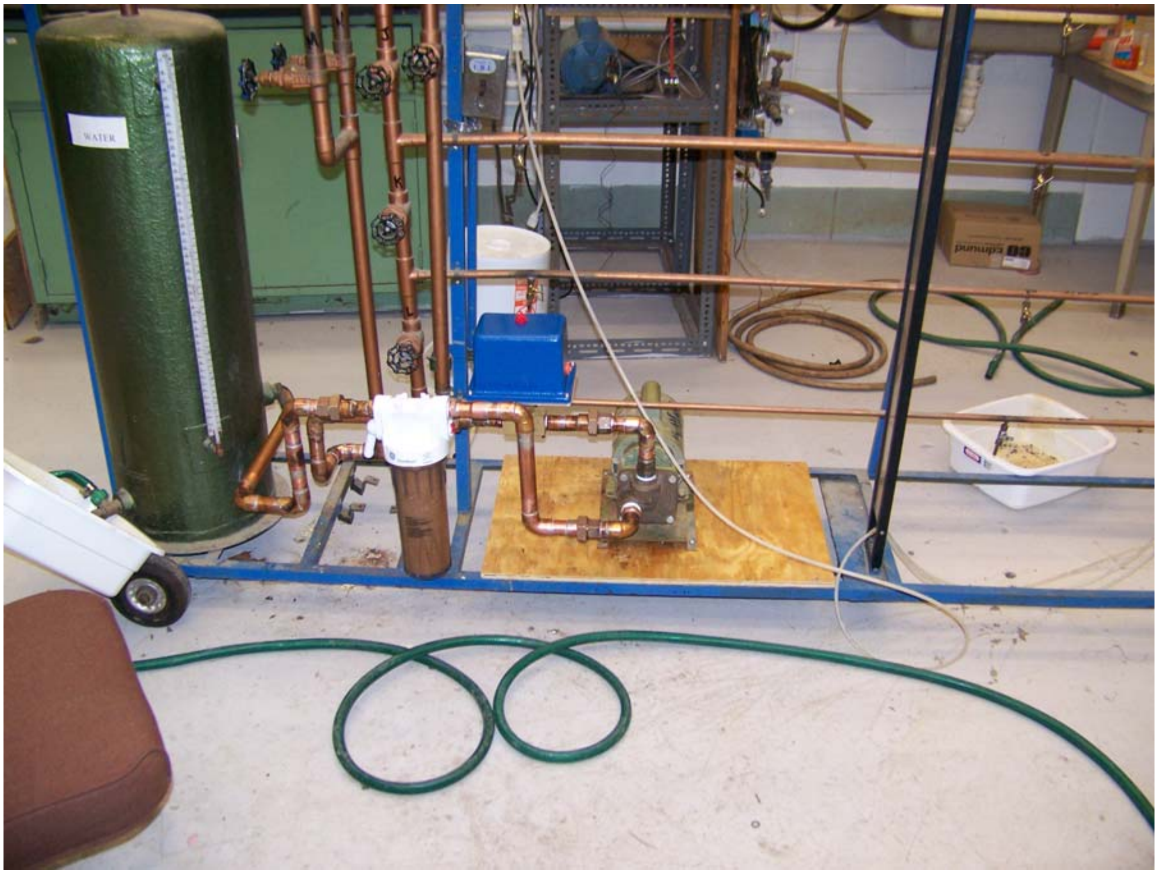

Figure 2 Friction Factor

Figure 3. Cooling Tower

Figure 4. Reaction Calorimeter