ChE laboratory

A MICROCOMPUTER BASED LABORATORY FOR TEACHING COMPUTER PROCESS CONTROL

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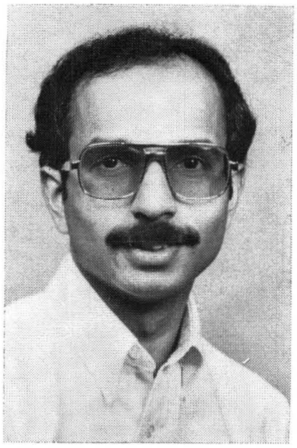
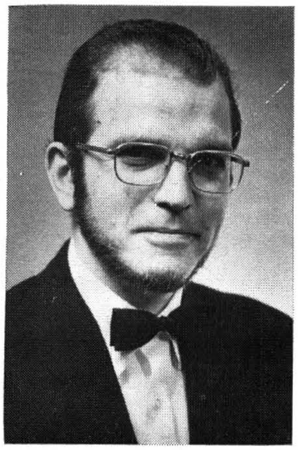
MOST SCHOOLS NOW REQUIRE undergraduate students in chemical engineering to take at least one course in process dynamics and control. The advent of the microcomputer has had a major impact in the instrumentation and control field, and this must be reflected in the curricula through added coverage of digital control systems and exposure to computer based data acquisition and control systems. In order to meet this demand, Washington University undertook the development of a new laboratory course specifically designed to teach the principles of process data acquisition and control using digital computers. The structure of the laboratory and the course are discussed in this article.





Babu Joseph received his PhD in chemical engineering from Case Western Reserve University and teaches courses in process design and process control, both at the undergraduate and graduate levels, at Washington University. His research interests are in the areas of process dynamics, control, simulation, and optimization, with special emphasis on the study of coal conversion process systems. His outside interests include reading, hiking, and canoeing. **(L)**

David L. Elliott received his PhD in system science from UCLA in 1969 and has taught mathematical systems at Washington University since 1971. Besides microcomputer applications, he is interested in the geometric approach to nonlinear systems, stemming from his work in the 1960s on the attitude control of underwater vehicles (U.S. Naval Ocean Systems Center) and the identification of enzyme-kinetics models for blood coagulation. He has published papers on bilinear systems, nonlinear observers, and linearization of systems by coordinate and feedback transformations. He is an editor of **Mathematical System Theory** and a former editor of the IEEE Control Society Newsletter. **(R)**

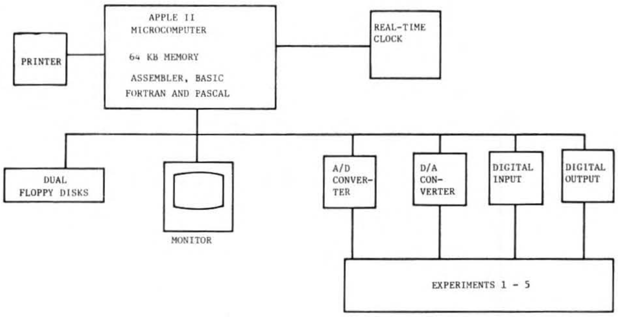


FIGURE 1. Computer system configuration.

COMPUTER SYSTEM CONFIGURATION

A decision was made early in the development of the laboratory to provide as much exposure as possible to the computing hardware used without getting engrossed in computer system architecture. We finally decided on using a set of dedicated Apple microcomputers, primarily because of their low cost, availability of plug-in compatible modules for data acquisition, and their popularity as a general purpose personal computer. The students like having their "own machine" to work with. It is also fun to work with after a few basic commands have been mastered. Particularly attractive is the graphics capability which allows data or results to be represented graphically using a very small set of commands. It does not hurt to have a few video games which the students can play during off hours.

Although the Apple has a wide variety of languages that could be used, we selected Applesoft, which is a floating point version of BASIC. Students who take the course have already been exposed to computers and we generally found that the students can be brought up to speed (including the use of graphics) in about two laboratory sessions. These sessions generally involve stepping through the tutorial manuals rather quickly. Unlike the manuals written for large computer systems, these manuals are very well written and quite easy for the students to follow. An important advantage of an interpretive language like BASIC is the ease with which small programs are written, edited, and debugged. The students can write and use mostly their own programs and yet run the experiment within the time allocated.

In addition to the computer, a disk drive allows students to store their programs and data. Each student is issued a diskette for his exclusive use.

For converting the Apple to a data acquisition device, two 'cards' which plug into the mother board of the Apple were added. One is a real-time clock which enables timing of the data acquisition. The other is an A-D/D-A manufactured by Mountain Computer which allows sixteen channels each of analog-to-digital and digital-to-analog conversion. These are limited to 8-bits of accuracy. For the experiments described here, this was sufficient. It is estimated that a basic system consisting of the Apple computer, one disk drive, a monitor, a clock and a AD/D-A board can be purchased for less than $3000 at current market prices. This, in fact, is the major cost of setting up the laboratory. The experiments themselves are homebuilt. Fig. 1 shows the sketch of a typical computer system configuration.

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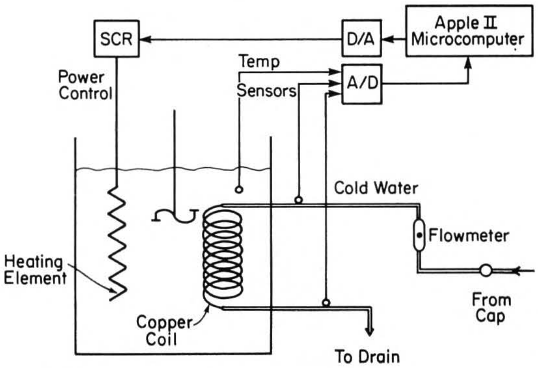

FIGURE 2. Temperature control experiment.

TABLE 1
List of Experiments

FIG.	EQUIPMENT USED	EXPERIMENTS*
2	Stirred Pot	• Calibration of a Temperature Sensor • Modeling the Dynamics of the Heated Tank • Feedback Control of Temperature
3	Pressurized Tank	• Calibration of Pressure Sensor • Dynamics of Tank Pressure • On-off Control of Pressure
4	Hot and Cold Water Mixing Tank	• Calibration of Level Sensor • Dynamics of Tank Level • Feedback Control of Tank Level • Multivariable Control of Level and Temperature
5	Heated Bar	• Data-logging Using a Multiplexer • Steady state Modeling • Feedback Control of Temperature • Cascade Control
6	pH Control	• Titration Curve Measurement • Feedback Control of pH • Nonlinear feedback Control of pH

EXPERIMENTAL SETUPS

The laboratory consists of five experimental setups, all built by undergraduate students as part of independent study projects. Figs. 2-6 show the schematic of each experimental setup and Table 1 lists the experiments performed with these setups.

The stirred-pot experiment shown in Fig. 2 is perhaps the easiest one to build and work with. The experiment centers around measurement and control of the temperature of water in a stirred coffee pot. The power input in the heating element can be manipulated by the computer. The students get a chance to develop some simple dynamic models and verify the theory by comparison with experimental data. Also this setup allows the study of different types of feedback control laws such as proportional only, PI, and PID.

The pressurized tank setup, shown in Fig. 3, offers an opportunity to study the behavior of surge vessels. The dynamics are easy to model and verify experimentally. The solenoid valves allow

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*A detailed manual describing the hardware used and detailing the experiments is available from the authors.

on-off control of tank pressure. The needle valves allow the time constants to be adjusted. This experimental setup is adapted from a similar experiment at the University of California, Santa Barbara.

Fig. 4 shows the schematic of an experiment to study multivariable control. This setup is discussed extensively in the recent book by W. H. Ray on advanced process control. The setup is used initially to study control of level alone and then to study the simultaneous control of level and temperature.

Fig. 5 shows the schematic of the heated-bar setup, another experiment that was adapted from the University of California at Santa Barbara. This setup introduces the concepts of multiplexing (using one channel to collect multiple data) ; it also enables the study of cascade control systems where the temperature at one end of the bar is controlled by adjusting the set point of an inner temperature control loop.

The pH control setup shown in Fig. 6 was built to demonstrate the effect of nonlinearities in feedback control. A simple nonlinear feedback controller can be designed to achieve good pH control in this case.

Additional equipment in the laboratory include a small analog computer which allows one to do hybrid computing. For example a simple third order process can be simulated on the analog controller and then hooked up with the digital computer for feedback control study.

COURSE OUTLINE

This course is taken mainly by seniors in chemical engineering and SSM (systems science and mathematics). It is assumed that the students have been exposed to a course in control so that they are familiar with basic concepts of feedback control, block diagrams representation, and transfer functions. The course, which consists of one hour lecture and three hours of laboratory, covers the topics shown in Table 2. Note that we give the students some exposure to advanced control such as feedforward, cascade, and multivariable control. During the last few weeks of the course, lecture time is devoted to cover topics of special interest to the students. Students are required to complete a project which may involve the design of new experiments with the existing equipment or by building new setups. This gives them an opportunity to explore any one aspect of the subject area in a little more depth. □

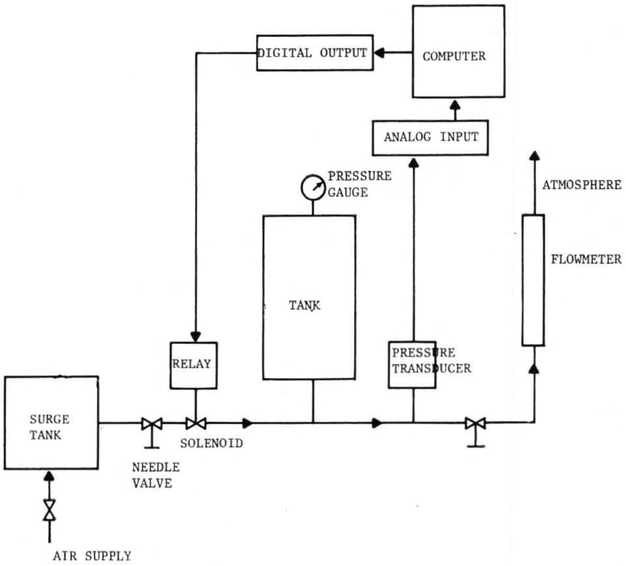

FIGURE 3. Pressure control.

TABLE 2
Course Outline

WEEK	LECTURE	LABORATORY
1	**Programming in Basic, Programming the Apple Computer**	
2	**Introduction to Real-Time Programming**	**Experiments using the Real-time Clock**
3	**Basics of Signal Processing A/D-D/A Conversion Fundamentals**	**Calibration of Temperature Sensor**
4	**Modeling of Dynamic Systems**	**Dynamics of the Temperature Sensor**
5	**Feedback Control of Processes**	**Modeling and Control Experiments based on each of the Setups in the Lab.**
6	**Analysis of Feedback Control Systems**	" "
7	**Feedforward Control**	" "
8	**Cascade Control**	" "
9	**Multivariable Control**	" "
10	**Current Methodology of Computer Control**	**Implementation and Testing of Advanced Control Methods**
11-14	**Advanced Topics of Special Interest such as Fast Fourier Transform, Digital Filtering, Identification, Multi-tasking, Computer Architecture, etc.**	**Project**

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to the National Science Foundation, the Apple Foundation and the School of Engineering at Washington University for providing financial support for the laboratory through equipment grants. Special thanks to our student, Dale Millard, who worked diligently on the hardware for the experiments and invented the power-controller circuit.

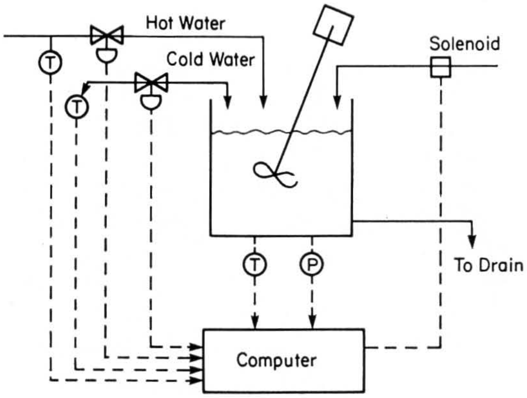

FIGURE 4. Temperature and level control.

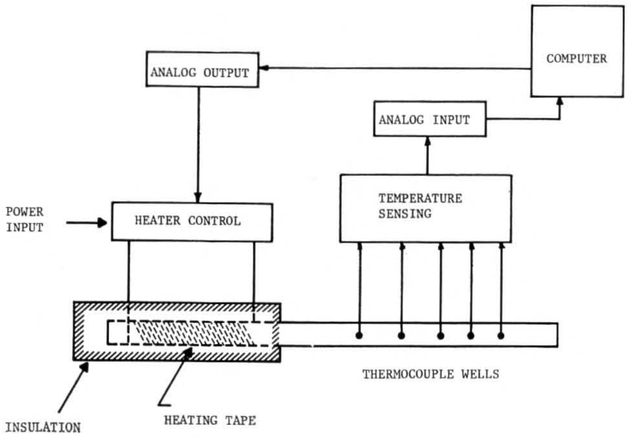

FIGURE 5. Heated bar experiment.

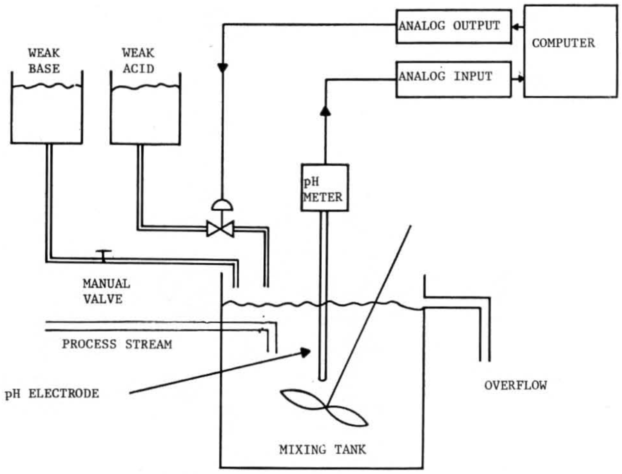

FIGURE 6. pH control experiment.

REFERENCES

The following books are used as reference material for the course.

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2. *Computer Process Control*, by P. Deshpande and R. H. Ash, ISA Publications (1981).
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4. *Minicomputers in Industrial Control*, T. J. Harrison, Ed., ISA Publications, Instrument Society of America (1978).
5. *Microcompressors for Measurement and Control*, by D. M. Auslander and P. Sagues, Osborne, McGraw-Hill (1981).
6. *Process Modeling, Simulation and Control for Chemical Engineers* by W. L. Luyben, McGraw-Hill (1973).

ChE book reviews

CHEMICAL AND PROCESS THERMODYNAMICS

by B. G. Kyle
Prentice-Hall, Inc., 1984, xvi + 512 pgs. $37.95

Reviewed by Truman S. Storvick
University of Missouri-Columbia

It appears that all chemical engineering thermodynamics textbooks are created equal. Each author intends to provide the student with an introduction to the subject and to show how specific applications in process design calculations can only be done by careful applications of the principles of equilibrium thermodynamics. Because this subject is the foundation of all chemical engineering, there have been many books written on the subject.

Professor Kyle has done what all authors have done with this subject the past two decades. He has taken the basic ingredient list assembled by Dodge [1] and by Hougen and Watson [2] and brought it up to date with new experimental data and worked examples. The ordering of the topics is not the same as one finds in the textbooks written by Smith and Van Ness [3] or by Sandler

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