A Course on

DIGITAL COMPUTER PROCESS CONTROL

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IN THE LAST DECADE advances in computer technology have had tremendous impacts on the various disciplines of engineering and science. In chemical engineering this has been particularly true in the area of process dynamics and process control. Over the past ten years both small and large process computers have become widely used to either support or replace conventional analog equipment. These computers are linked directly to the process units and can be used to continuously monitor and make decisions about the operation and the control of the process. The memory, logic and computational capabilities of the digital computer combined with the flexibility of modern digital programming systems make possible the implementation of very sophisticated supervisory and control strategies that were difficult if not impossible under conventional analog instrumentation. The tremendous potential offered by the process computer has served to establish the specialized area of computer control as an increasingly important segment of chemical engineering education as well as practice.

AT THE UNIVERSITY OF TENNESSEE numerous research and educational programs have been established in the general area of process computers. One such program is a three-hour course entitled "Digital Computer Process Control" currently a graduate level course offered to graduate and advanced undergraduate students. The major objectives of the course are:

- To introduce students to the concept of data acquisition and control using the process computer.
- To describe in detail current industrial practices using process computers.
- To integrate the related disciplines and provide a foundation upon which to see beyond current practices.

COURSE OUTLINE

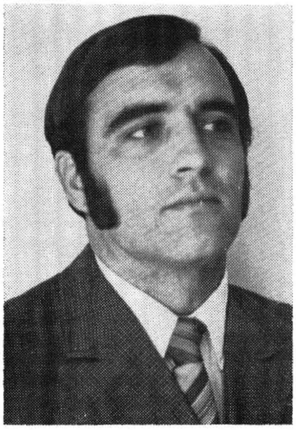
The objectives of the course are achieved through several types of study. Formal lectures are given supplemented by laboratory demonstrations. In addition, homework is given and each student is assigned a term project which is presented to the class at the end of the quarter. The text currently used is entitled *Digital Computer Process Control* by Cecil L. Smith published by International Textbooks.

The lecture material is outlined in Table I. It consists of four sections. The first is primarily an introduction to the use of digital computers in process control. The concepts of digital data acquisition, direct digital control, supervisory control and hierarchial control are discussed and examples cited.

TABLE I
General Course Outline

A. Introduction to the Concept of Digital Data Acquisition and Control
B. A Close Look at the Process Computer System
  1. Hardware Fundamentals
  2. Real-time vs. Batch Programming
C. State of the Art of Current Industrial Control Practices
  1. Standard Algorithms—Design and Selection
  2. Controller Tuning and Evaluation
  3. Selecting Sample Time
  4. Dealing with Process Noise
  5. Computer Back-up
D. Advanced Control Strategy
  1. Simple Modification of Standard Algorithms
  2. Feedforward and Cascade Control
  3. Dead Time Control
  4. Multivariable Control
  5. Predictive Control
  6. Z-Transfer Modeling and Controlled Design
  7. Survey of Modern Control Theory

The next section is devoted to the process computer itself. Most engineers are very familiar with the large data processing computers and have used such systems extensively for scientific programming; however, few have any exposure to real-time process computers. Several lectures are devoted to discussing computer hardware systems with the purpose of describing the process com-



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His teaching and research interests include process modeling, process control, and optimization and computer programming. He has consulted and authored numerous articles in the area of computer control. He has co-taught numerous industrial short courses in this area including the "Today Series" of the AIChE.

puter and providing the student with some of the computer jargon necessary to work in the area of computer control. Real-time software systems are also discussed and contrasted to standard engineering programming.

The third section is a discussion of the current industrial practices in the area of computer process control. In this section the standard control algorithms are developed and discussed in detail. Practical considerations such as process modeling, algorithm selection, selection of sample time, and controller tuning and evaluaton are emphasized along with other practical considerations such as dealing with process noise and handling computer failures.

The final section is devoted to advanced control strategies and deals with those strategies and techniques which better utilize the tremendous potential of the digital computer. Unfortunately the current state of the art in terms of industrial applications is in most cases little more than digital simulations of conventional analog instrumentation.

THE ADVANCED CONTROL TOPICS explored in this section fall generally in two categories: advanced but simple and the advanced but sophisticated. The advanced but simple techniques include simple modifications and extensions of conventional practices which are simple to implement on the digital computer but would be difficult if not impossible to implement using analog equipment (such as the modified derivative mode, modified proportional mode, anti-reset computations, programmed tuning parameters, automatic tuning and calibration, etc.). The advanced but simple also includes strategy such as feedforward control, cascade control, dead time control and multivariable control. Such techniques have been implemented using conventional equipment but are considered sophisticated. They can, however, be very simple to implement on the process computer and usually require no additional hardware and in some cases can be implemented almost as easily as the standard three mode algorithm. The advanced but sophisticated section includes a survey of strategies which are fundamentally different than the conventional practice. It includes feedforward/feedback predictive algorithms, z-transform modeling and controller design, and a brief look at what modern control theory has to offer.

SPECIAL PROJECTS

AN INTEGRAL PART of the course as taught at the University of Tennessee is the term projects assigned to each student. The projects serve to integrate the material presented in class and also adjust to the various backgrounds and interests of the students. The projects are normally small research projects which include either a simulation oriented study or a laboratory oriented study using the process computer facilities discussed below. Project studies are summarized as the problem areas appear in the lecture material. Normally by midquarter all students have selected a topic and are expected to complete the study for a formal presentation to the entire class by the end of the quarter. Table II lists some of the projects which have been explored in previous quarters.

The tremendous potential of the process computer has established the computer control area as an increasingly important part of ChE education and practice.

TABLE II
Typical Term Projects Topics

- Tuning Cascade Control Loops
- Effect of Mode'ing Errors in First-Order Lag Plus Dead Time Tuning Correlations
- Tuning Correlations for a Second Order Lag Plus Dead Time Plant Model
- A General Linear Regression Program for Discrete Process Modeling
- Effect of Sample Time on the Digital Smith Predictor
- Effect of Model Errors on the Digital Smith Dead Time Compensator
- Effect of Model Errors on the Analytical Predictor
- Effect of Derivative and Proportional Mode Modification on Controller Tuning and Performance
- Designing of a Non-interacting Integral Mode
- Multivariable Control Using a Simple Discrete Model
- Use of the Predictor Approach to Remove Process Order
- Effect of Process Constraints on Multivariable Control
- Effect of Dead Time on Multivariable Strategy

COMPUTER AND LAB FACILITIES

THE CLASS DEMONSTRATIONS and many of the term projects involve the use of the Departmental process computer and laboratory facilities. The computer facility (described in Table III) is a general purpose data acquisition and control utility which serves the real-time computational need of the various research and educational programs of the Department of Chemical and Metallurgical Engineering. It consists of a medium size digital computer, an analog interface system and an extensive communication network (Figure 1) which through a patch panel arrangement can service equipment in 10 different laboratories. Table IV lists some of the laboratory facilities currently using the computer. These diverse applications provide numerous examples of techiques of digital data acquisition and control covered in the lecture. Also, the computer control laboratory which contains several units designed specially for industrial control studies is used for advanced demonstration and can be used in the term projects for on-line studies.

TABLE III
Process Computer System

COMPUTER:
PDP 15/35 (manufactured by Digital Equipment Corporation) 16k core memory with Automatic Priority Interrupt and Extended Arithmeatic Element.

BULK STORAGE:
One 262,000 word fixed head disk (RS15 DEC disk) two 148,000 word magnetic tape drives (TU56 DEC tape).

I/O FACILITIES:
High speed paper tape reader/punch, one high speed DEC writer and keyboard, four teletype units, one dataphone modem.

ANALOG INTERFACE:
32 channels voltage input with a programmable gain amplifier (gains of 1, 5, 10, 100, 500, and 1000). Operated with a 12 bit analog to digital converter. Five 10 bit digital to analog converters (output range = ± 10v). Eighteen double pole computer operated relays. Eighteen contact sensors which operate on the hardware interrupt system.

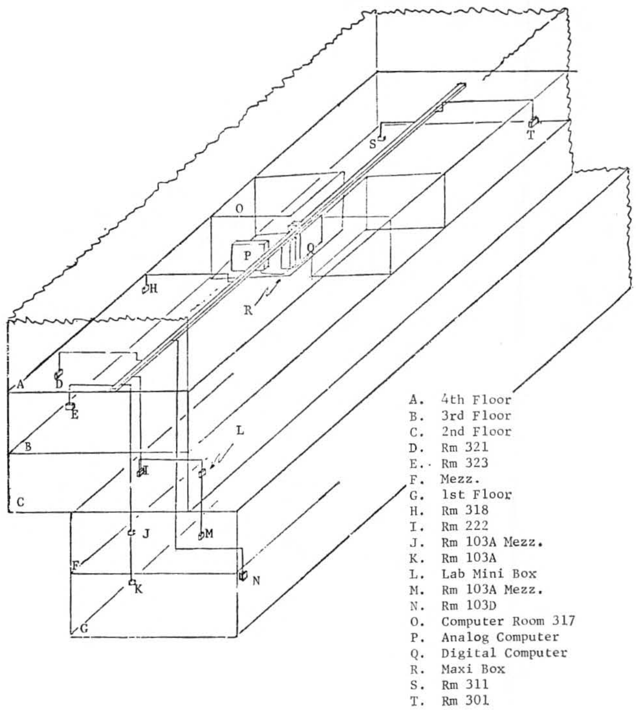

FIGURE 1

Process Computer Laboratory Communication System

LAB COMMUNICATION:
The various laboratories are linked to the computer room and can be patched to available computer hardware at the maxi-box termination panel (see Figure 1). Each link contains 24 high quality analog channels and one teletype channel.

SOFTWARE:
The system supports both a data processing monitor and a real-time monitor system. Most real-time programming can be done in FORTRAN.

TABLE IV
Laboratories Using Process Computer Facility

ANALOG COMPUTER LAB:

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Now . . . it is very clear we are moving in the direction of the Master's degree becoming the first professional degree.

Let's take a chemical engineer. He would come in with a background degree where he could pick up on the graduate level about 15 hours of chemical engineering and take the other 15 hours in his choice in various courses related to, e.g., business management. We want to give him a Master of Engineering degree. It is not accreditable on the advanced basis but I would be willing to try to make it accreditable using a basic criteria. This is a typical example of one of the reasons I feel it is so important that we convince the ECPD group and the ECPD-EE&A Committee that schools should be given the right, at least for the next four or five years, to make their own decisions as to whether they want their master degrees accredited on the basic level or on the advanced level. There is an ECPD-EE&A sub-committee of which I am a member currently working on this, but I don't know what the result will be because I haven't heard from the other members. However, I think if we can get this kind of a flexibility in as we start, then we chemical engineers will be able to do what I believe AIChE wants to do. That is, move very slowly into the area of advanced program accreditation recognizing clearly the possibility that we are therefore heading toward the masters degree as the first professional degree. □

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The analog and digital computer can be linked for low speed hybrid computation. The analog is used extensively for laboratory simulation for convenient program check out.

X-RAY DIFFRACTION LAB:
The computer is used to collect and process x-ray diffraction data. Future plans include the automation of a three-axis goniometer.

MASS TRANSFER LAB:
The computer is currently linked to a gas chromatograph for data collection and analysis. Future plans include the complete automation of the chromatograph and sampler.

CALORIMETRY LAB:
The computer is currently linked to an adiabatic calorimeter for both temperature data acquisition and control. Future plans include the automation of a pulse calorimeter.

HYGROMETRY LAB:
The computer is linked to a frost point hydrometer for data collection and periodic temperature display on a special laboratory console.

PROCESS DYNAMICS LAB:
The computer is linked to a small scale multi-stage flash evaporator and to a small packed column to collect process data (temperature, pressure, flow rate, concentration).

COMPUTER CONTROL LAB:
The computer is linked to four small process units (distillation column, batch reactor, a temperature control system, and a small flow system) for research of advanced direct digital control applications.

FUTURE PLANS:
Numerous additional links are planned for the future. They include the following laboratories and facilities: Scanning electron microscope (data acquisition); zone refiner (control); Instron (data acquisition); mass spectrometer (data acquisition); zone centrifugation lab (data acquisition).

CONCLUSIONS

The course has presently been taught three times at the University of Tennessee. It has been modified each time it has been presented to include recent developments in the field as well as to add additional demonstrations and examples. The course has been well received by students in all areas of chemical engineering and has also been attended by students outside the Department. The course is primarily a survey of process computer application and an introduction to modern control theory and practice. It has been extremely helpful for students interested in pursuing research in the area of computer control by providing a broad picture of various disciplines necessary to a solid background in digital process control. □