NEWSLETTER

CAST

COMPUTING AND SYSTEMS TECHNOLOGY DIVISION

American Institute of Chemical Engineers

1908 1983 SEVENTY-FIVE YEARS OF PROGRESS

VOLUME 6 No. 1 FEBRUARY 1983

CHAIRMAN'MESSAGE

Prof. David M. Himmelblau
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In assuming the position as Chairman of the CAST Division of the AIChE, I would like to start the year out by stirring up some interest (and perhaps controversy) in achieving greater participation of CAST members in existing and potential CAST activities. After reviewing the CAST activities in both the areas of programming papers for meetings and publications, there seems to exist (at least in my opinion) a significant sector of our membership who feel that CAST neglects their interests. If a substantial number of members feel left out, CAST should take some steps to correct the situation. We want to avoid under all circumstances creating a dichotomy with a small group on the "inside" and the rest of the members on the "outside".

Two expressions of such feelings are that CAST

1) should place more emphasis and status on applications in their programming and publications, and
2) should broaden the participation of the membership in CAST activities.

Both of these attitudes reflect a misalignment of the functions of CAST with respect to its' membership. Furthermore, I believe that both can be alleviated by greater membership participation in CAST programs. By programs I mean not only ongoing programs, but programs that members feel would be of interest to them to a sufficient degree that they would be willing to help organize sessions at AIChE meetings and write articles for AIChE publications.

Mike Tayyabkhan, our new first Vice-Chairman, has been asked to establish a data base of names of individuals who would like to work in CAST activities, either existing or those that might be proposed to be accomplished. Get in touch with him (Mobile Research & Development, P.O. Box 1026, Princeton, NJ 08540) if you would like to work on some existing activity, refocus an existing activity, or start a new activity, or just help with our programming, publications, or membership functions.

PUBLICATIONS BOARD REPORT

Dr. Edward Gordon

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The future of CAST publications was the major topic of the CAST Executive Committee meeting held on November 16, 1982. Since the last election results announced at the meeting are not reported elsewhere in this newsletter, they are as follows: Ed Rosen was elected as Second Vice Chairman.

John Hale and Art Westerberg were selected as Directors and Joe Zemaitis was reelected as Secretary Treasurer. Dave Himmelblau and Mike Tayyabkhan automatically advance to Chairman and First Vice Chairman.

The AIChE Publications board met on November 15, 1982 and made favorable recommendations regarding Quarterly magazines. They are looking forward to one each from the Computing and Systems Technology; Food, Pharmaceutical, and Bioengineering; and the Heat Transfer and Energy Conversion Divisions. The reactions to the three current Quarterlies has been quite favorable. They plan to make a formal recommendation to the AIChE Council by the end of 1983.

The CAST Executive Committee then decided to expand the current Newsletter within the limits of the available budget until formal action is completed regarding a Quarterly for CAST. This issue is roughly double the normal size of the CAST Newsletter. It contains reviews of recent advances in Systems and Process Control which were generated by my picking the portions of recent articles by Tom Edgar and Harmon Ray which should be of wide interest to our membership.

We had planned to have condensations of several papers presented at CAST sessions but there was not enough time before the Newsletter deadline to get all of the approvals required. Instead, at the suggestion of the CAST Chairman reviews of two of the papers in the Large Scale Optimization sessions with broader appeal to CAST membership were prepared. All of the papers from the Optimization sessions are scheduled to be published in Computers and Chemical Engineering. The two papers reviewed in this Newsletter contain much information which should appeal to a substantial portion of the CAST membership in contrast to the highly technical and more specialized subject matter in the other papers.

For future issues we need some volunteers who will do reviews of the more practical aspects of the papers presented at the various CAST sessions. Since most of the papers are devoted to rather specialized areas, there is a strong need to make our membership aware of the contributions presented without getting into the details which belong in a technical journal.

This need was indicated in the responses containing preferences of our membership. Nearly two hundred responses were received which were largely favorable to the proposed Quarterly Magazine. The responses are summarized in Table I. Over half of the responders have been AIChE members over 10 years, yet many have attended few or no AIChE National meetings.

To satisfy all of these desires, we will need a number of volunteers to review papers in the various computing and systems technology oriented magazines. The goal is to have enough volunteers so that each one would have to prepare only one or two reviews of items with widespread interest in our membership. During the transition period we can determine how useful the material presented is to our membership and how many are willing to digest the virtual torrent of publications in the areas we are interested in to make others aware of significant contributions.

The Directory which was optimistically planned for January 1983 is slowly progressing towards compeltion. A number of anticipated contributions are still being anticipated as of January 30, 1983. At the current rate of progress, April 1983 is the revised target date.

TABLE I

Summary of Preference Survey Responses

	0	1	2	3	4	5	6-9	10-15	16-20	21+
Years of AIChE Membership	0	5	13	12	11	13	25	38	20	46
Number of AIChE Meetings	31	23	22	18	12	8	15	15	7	6

CAST Areas	Number of Responses
Systems and Applied Math	82
Systems and Process Control	66
Computers in Management and Information Systems	49

	Yes	No
Ever used microfiche?	98	81

Would you like the Proposed Quarterly to Contain the Following?

	Yes	No
Frequent reviews of new ideas and techniques in each of a number of specialty areas	136	4
Reviews of the new ideas and discussion of papers at each of the CAST sessions at A.I.Ch.E. National meetings.	115	13
Condensations of the papers at CAST sessions containing the more important contributions of each paper	126	13
Complete test of papers which describe: User experiences with a new computational technique	83	39
Computation techniques	81	30
New applications of standard packages or widely used techniques	84	28
New computational techniques	90	32
Reviews of the CAST related content of a list of computing and applications oriented journals and magazines.	103	15
New software and hardware products available from vendors	103	17
User experiences with available commercial software	117	12
User experiences with available computers, microcomputers, programmable calculators	104	21
Book Reviews	90	17
CAST session programming plans calls for papers for approved sessions preliminary planning of future sessions	106	12
Algorithms for new computational techniques	106	19
Review articles summarizing new contributions in dissertations	90	22
Review of research activities underway at universities and in industry	106	17

CAST Awards
Solicitation of Nomination

Please use the form on the next two pages to submit your nomination to Ed Rosen by March 31, 1983. Use a separate copy of the form for each nomination.

Computing in Chemical Engineering Award

This award is given to recognize outstanding contributions in the application of computing and systems technology to Chemical Engineering. It is normally awarded annually and consists of a plaque and a check for $1500. Funding for the three years (1982-84) has been provided by Simulation Science of Fullerton, California, and Intergraph Corporation, Huntsville, Alabama. The 1982 Awardee was Lawrence B. Evans of ASPEN Tech. formerly Professor of Chemical Engineering at MIT and leader of the ASPEN Project at MIT. The 1981 Awardee was Richard S.H. Mah, Professor of Chemical Engineering at Northwestern University. The 1980 Awardee was Brice Carnahan, at the University of Michigan. The 1979 Awardee, Richard R. Hughes at the University of Wisconsin, was the first recipient of the award.

Ted Peterson Student Paper Award

This award is given to an individual for published work in the application of computing and systems technology to Chemical Engineering. The work must have been done by the individual while pursuing graduate or undergraduate studies in Chemical Engineering. The award will consist of $500 and a plaque and is normally awarded annually. This is a new award and the first award is expected to be made in 1983 at the Diamond Jubilee Meeting in Washington, DC. It is currently being supported by IBM and ChemShare, Inc.

ORDERING MICROFICHE

Microfiche are available from AIChE headquarters for 1 year after the meeting. Prices: $1.50 per Fiche for members - $3.00 for non-members. For additional information call AIChE Technical Publications Department (212) 705-~~7335.~~ 7657

CAST Related Microfiche for the Winter Annual Meeting, Los Angeles, November 14-19, 1982 are:

Session 9 ✓	Dynamic Process Models For Control Systems b,c: Fiche 58; d: Fiche 3; f: Fiche 4
Session 10 ✓	New Approaches To Process Control Problems a,e: Fiche 3; b,c: Fiche 4; d,g,h: Fiche 2
Session 11	Process Data Reconciliation and Rectification a,c,d: Fiche 12; b,e: Fiche 13
Session 13	Computers In Process Design and Analysis a,d,f: Fiche 15; c,e: Fiche 16
Session 18	Computer Modeling and Simulation-Are They Cost Effective? a,b,c,e,f: Fiche 14
Session 19 ✓	Interface Between Process Design and Process Control e,f,g: Fiche 1
Session 20	Computers In Process Design and Analysis a,b,f: Fiche 59; c,d,e: Fiche 60
Session 21	Recent Advances In Applied Mathematics and Numerical Methods c: Fiche 13; e: Fiche 95; g: Fiche 14
Session 22	The Status Of Large Scale Optimization I e,c: Fiche 51; b: Fiche 11
Session 23	The Status Of Large Scale Optimization II a,b,c: Fiche 10; d,e: Fiche 11
Session 24	Optimization Of Entire Plant Operations a,e: Fiche 9; b,d: Fiche 88
Session 69	Simulation and Modeling a,e: Fiche 46; b,f: Fiche 45; c: Fiche 48

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

1983 AWARD NOMINATION FORM*

A. BACKGROUND DATA

1. Name of the Award ______________________________ Today's Date ______________

2. Name of Nominee ______________________________ Date of Birth ______________

3. Present Position (exact title) ______________________________

   Address ______________________________
   Institution or Company   City and State   Zip

4. Education:

Institution	Degree Received	Year Received	Field

5. Positions Held:

Company or Institution	Position or Title	Dates

6. Academic and Professional Honors (include awards, memberships in honorary societies and fraternities, prizes) and date the honor was received.

7. Technical and Professional Society Memberships and Offices

8. Sponsor's Name and Address ______________________________

   ______________ Sponsor's Signature ______________

* A person may be nominated for only one award in a given year.

B. CITATION

1. A brief statement, not to exceed 250 words, of why the candidate should receive this award. (Use separate sheet of paper.)

2. Proposed citation (not more than 25 carefully edited words that reflect specific accomplishments).

C. QUALIFICATIONS

Each award has a different set of qualifications. These are described in the awards brochure. After reading them, please fill in the following information on the nominee where appropriate. Use a separate sheet for each item if necessary.

1. Selected bibliography (include books, patents, and major papers published.)

2. Specific identification and evaluation of the accomplishments on which the nomination is based.

3. If the nominee has previously received any award from AIChE or one of its Divisions, an explicit statement of *new* accomplishments or work over and above those cited for the earlier award(s) must be included.

4. Other pertinent information.

D. SUPPORTING LETTERS AND DOCUMENTS

List of no more than five individuals whose letters are attached.

	Name	Affiliation
1.		
2.		
3.		
4.		
5.		

Please send 8 copies of this form and supplemental sheets by March 31 to E. M. Rosen, Monsanto Company, Mail Zone F2EB, 800 N. Lindbergh Boulevard, St. Louis, Missouri 63167.

AN INTRODUCTION TO MULTIVARIABLE PROCESS CONTROL

W. Harmon Ray University of Wisconsin

HISTORICAL PERSPECTIVE[1]

In order to understand the present process control status, it is useful to recall the history of this field. From its beginnings in antiquity (Mayr, 1970; Bennett, 1974; Fuller, 1976), until the early 1960's, process control was based almost entirely on mechanical, electric, or pneumatic analog controllers that were usually designed with linear single-input, single-output considerations. Hardware limitation, economic cost, and the dearth of applicable theory usually precluded anything more complex than these simple schemes. Because many large-scale industrial processes are endowed by nature with large time constants, open-loop stability, and significant damping of fluctuations through mixing the storage tanks, such simple control schemes work well for perhaps 80% of the control loops one might encounter. Of the remaining 20%, most controllers were considered marginally acceptable during this early period because there were few environmental regulations; product specifications were quite loose; and intermediate blending tanks could cover many of the sins of inadequate control. Thus the costs of even small sophistications in control were high and economic incentives for improved control were comparatively low.

Over the last 10 to 15 years, there has been a dramatic change. Industrial processes are now predominantly continuous with large throughputs, highly integrated with respect to energy and material flows, constrained tightly by high-performance process specifications, and under intense governmental safety and environmental emission regulations. All of these factors combine to produce more difficult process control problems while at the same time requiring better controller performance. Significant time periods with off-spec product, excessive environmental emissions, or process shutdowns due to control system failure can produce catastropic economic consequences due to the enormous economic multipliers characteristic of high-through put, continuous processes. This produces large economic incentives for reliable, high-quality control systems in modern industrial plants.

Another recent development in process control is that the performance of real-time digital computers suitable for on-line control has improved significantly while prices have fallen drastically. These computer price reductions have persisted over the last decade, in spite of hardware improvements, through more reliable electronics and the more than 100% increase in the consumer price index due to inflation. As a result, the process control computer is now such a small part of the overall process capital costs that installation of a powerful minicomputer or microcomputer system can often be easily justified on the basis of improved safety and manpower savings.

These developments have produced rather significant changes in process control education, research, and industrial practice. To see how this has evolved we shall discuss the development of process control from its infancy in 1940 to the present.

When process control was introduced into the chemical engineering curriculum in the 1940's (Hougen, 1977),

[1] This material is taken from (Ray, 1982)

TABLE 1

Historical Trends in Process Control (1940–1980)

Time period	Curricula in education		Character of research		Industrial practice	
	Undergraduate	Graduate	Topics	Background of researcher	Topics	Background of practitioner
1940	Measurement controller hardware PID control Linear systems Controller tuning Cascade control/ ratio control	Nonlinear SISO* analysis	Measurement hardware Controller hardware Nonlinear SISO systems Process identification (SISO) Controller tuning Analog computation	Instrumentation Electrical engineering	Measurement hardware Controller hardware Controller tuning Cascade control/ ratio control	Instrumentation Electrical engineering Process engineering
1950	Step, frequency response for identification Transform domain Stability Analog computation	Analog computation Feedforward control Pulse testing	Stability Feedforward control Digital computation Process computer control		Feedforward control	
1960	Nonlinear SISO analysis Pulse testing	Digital simulation Adaptive control Optimal control State estimation Multivariable systems	Adaptive control Optimal control Multivariable systems State estimation Distributed parameter systems Computer-aided design	Applied mathematics Computer application Process engineering	Digital computer control Multivariable controller installations	Process control Process engineering
1970	Feedforward control Digital simulation Process computer control Multivariable systems	Distributed parameter systems Process computer control Advanced control applications	Advanced control applications Distributed computer control Interacting large-scale systems Design control applications	Process dynamics Control theory Real-time computing	Advanced control applications Distributed computer control	Process control Minicomputer applications
1980		Distributed computer control	Energy management Human factors Reliability, robustness		Human factors Energy management	

* SISO = single-input, single-output.

the analysis of dynamic systems was confined to single-input, single- output linear systems, and control system designs were based upon the classical results of Nyquist (1932), Bode (1945), Ziegler and Nichols (1942), and others. These early techniques were simply adopted from electrical and communications engineering and were applied to process control problems. As indicated in Table 1, these classical concepts remained the principal thrust of undergraduate process control courses from the 1940's to the mid-1970's.

Graduate courses in process control began to include considerations of time-domain analysis, multivariable control, and optimal control in the mid-1960s (Lapidus and Luus, 1967; Koppel, 1968; Gould, 1969; Douglas, 1972) in response to rapid developments in control theory arising from aerospace and electronics applications. Unfortunately, most of the control algorithms arising from so-called "modern control theory" required on-line digital computers to implement them, and in the 1960s these were not generally available in universities due to the high hardware cost. Thus, no real time implementation experience was possible as part of these courses, and "modern process control" adopted more of a mathematical than engineering flavor.

In the early 1970s, as computer hardware prices dropped, both undergraduate and graduate courses in process control began to include real-time computing data acquisition and control as part of the laboratory experience (e.g., Fisher, 1971; Christensen and Vargo, 1971; Westerberg, 1971). These early efforts stimulated many other departments to acquire real-time computing facilities so that today about half of the chemical engineering departments in the U.S. and Canada offer hands-on process computer control experience in their courses (Seborg, 1980). Current trends in process control education seems to be toward undergraduate courses that introduce the concepts of multivariable system dynamics and control and provide a solid lab experience, including real-time computer data acquisition and control (e.g., Morari and Ray, 1980). Similarly, graduate courses are balancing discussions of recent theoretical results with the practical aspects of implementation (Morari and Ray, 1979; Ray, 1981c).

The advent of powerful, inexpensive minicomputers with easily used interactive graphics has led to the evolution of many standard programs for interactive, computer-aided control system design. Such computer-aided design modules are beginning to find their way into the process control curriculum so that students may now routinely carry out realistic and practical controller design studies for complex processes such as distillation columns, stirred tanks, gas storage networks, etc. Computerized design procedures involving Bode plots, Nyquist diagrams, or inverse Nyquist arrays can be used in tandem with identification procedures (e.g., step, pulse, and frequency response methods) to allow the student to study the dynamics and control of a process in a rather short time. It appears that future growth in this direction will be extensive.

As indicated in Table 1, process control research in the 1940s quickly found its way into the classroom and into industrial practice. In fact, Donald Eckman, one of the leading figures in process control of this era, noted an "inverse gap" between theory and practice when he wrote in 1945 (Eckman, 1945 p. vii): "...instrumentation and automatic control have progressed to the development of sophisticated control mechanisms and methods without a parallel development of a generally useful foundation of theory." As we know all too well, process control theory soon grew without bound, and has been either ahead of or orthogonal to industrial practice for some 15-20 years.

The early process control researcher was likely an electrical or instrumentation engineer and was responsible for establishing the art of classical process control. Beginning in the early 1960s, the ranks of process control researchers began to be filled with applied mathematicians and digital computer simulation people. This established a sharp split in philosophy in the field between the traditional process engineers who touted "simple controllers and learning the process by plant experience" versus the applied mathematician/numerical analyst who espoused "a priori models, digital simulation, and modern control theory" as the road to success. This schism has persisted until recently, when the logical middle ground between the two extreme views has been taken by researchers well-steeped in theory but who feel that a good fundamental understanding of process dynamics, process measurement, and real-time computing hardware is necessary for practical control system design. It appears that this new breed of researcher is rapidly mending the philosophical division in process control research.

The current directions of process control research would seem to be motivated by a number of factors:

- the existence of a wealth or relatively unused control theory
- the ready availability of inexpensive, powerful mini- and microcomputers
- the emergence of large economic incentives for energy conservation and heat integration in the process industries.

Quite naturally, this has led to new substantial research initiatives in many areas such as:

- application of advanced control concepts to many difficult-to-control processes (e.g., packed-bed reactors, processes with large time delays, etc.)
- study of distributed mini- and microcomputers networks for control implementation
- research in human factors engineering to determine the best means for computer-human interactions and to facilitate operator acceptance of computer control systems
- control of systems of interacting processing units
- a study of the influence of process design decisions on the process dynamics and control structure of the resulting plant.

In contrast, to much of the process control research of the 1960s (which arose chiefly from the very alluring and charismatic modern control theory necessary for aerospace and communications applications), much of the motivation for the research directions listed above arises from a perceived need in the process industries. It is to be hoped that this trend will continue and may serve to narrow the long-lamented gap between theory and practice.

Although it is always dangerous to attempt to characterize the practice of engineering in industry, where so much of the technology is documented in confidential company reports, some of the principal developments in the industrial practice of process control are outlined in Table 1. The table should be viewed with a slight blurring of dates because of the great disparity in rate of development in process control among the various industries (petroleum, chemical, pharmaceutical, paper, steel, etc.). For example, some industries have had process computer control in their plants since the early 1960s while other industries did not take this step until a decade or two later.

Perhaps the most interesting trend shown in Table 1 is that there are a significant number of theoretical developments in the "research" column which have not yet found more than token application in industrial practice. This may be due to a basic impracticability of some methods for process control application or, alternatively, because of the time delay between theory and implementation.

In any case, it appears that the time is ripe for a new renaissance in bringing advanced control concepts into process control practice. This has been made possible by two factors. First, significant economic incentives for tighter process control have come at a time of a virtual explosion in process mini/microcomputers technology. Secondly, those engineers educated in modern process control theory are now reaching positions of responsibility in industry and can knowledgeably assess the practical advantages and disadvantages of these theoretical developments. Thus it is examination time; those advanced process control techniques which cannot perform well in practice will remain intellectual curiosities while those approaches which show promise in practice will likely find broader application in the future.

Some Current Process Control Problems

In the spirit of having practical process control problems influence discussions of process control research, we shall preface our survey of theoretical developments with a presentation of some current important motivating problems. These

ALTERNATIVES TO RAPID ON-LINE MEASUREMENT

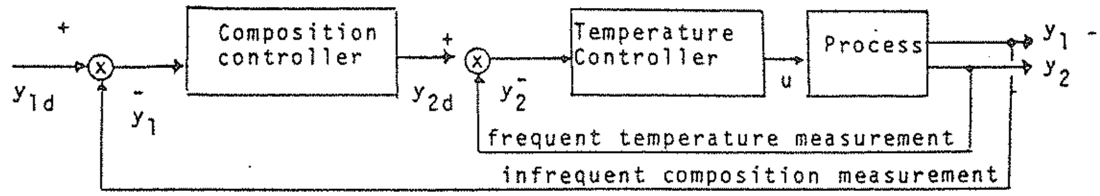

Figure 1. Inferential cascade control

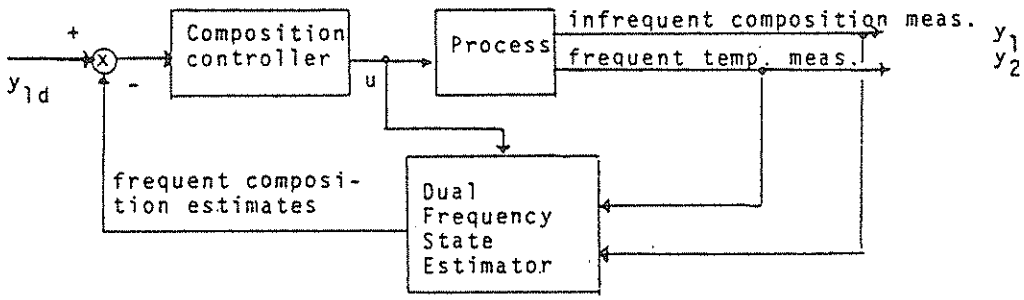

Figure 2. State estimation

can be outlined as follows:

1. <u>Complete Plant Scheduling and Control</u>

Although this topic will be treated by other reviews (cf. Morari,), it is the ultimate goal of process control research. Present computer network technology would allow multilevel and multitime scale computer control of complete plants and even entire divisions of a company. This would involve raw material allocation and long range production scheduling at one extreme and real time control of individual process units at the other. Two way communications in this network would allow weekly or monthly averaged product distributions to be produced while minimizing production costs and dynamic upsets to the plants. To accomplish this ultimate goal, both short range dynamic control software and hierarchical management and control strategies still require development.

2. <u>Control Loop interactions and Multi-variable Controller Design</u>.

In spite of more than a quarter century of research on this topic, there are still no completely reliable methods for a loop pairing, controller tuning and compensator design for interacting control loops. Rather, there exist a variety of test criteria for loop pairings and a host of fragmented approaches and recipes for controller design and tuning. As yet no comprehensive systematic approach to the solution of this most common design problem has evolved and been accepted.

3. <u>A Dearth of On-line Process Sensors (Inferential Control, State Estimation)</u>.

Although recent advances in instrumentation technology have been impressive, it is still very often the case that all the desired state or output variables cannot be measured on-line and control schemes must be designed to function without the desired measurements. Perhaps the most common examples involve composition measurements which are either absent or infrequent. In these cases secondary measurements and an inferential control scheme (e.g., the use of target tray temperature measurements to achieve desired product compositions in distillation column control) can be used (cf. Fig. 1). Alternatively, if a good dynamic model is available, on-line "state estimation" (such as

Kalman filtering) can be used to reconstruct the missing measurements and then a conventional feedback controller operating on a mixture of measurements and state estimates may be used (cf. Fig. 2). Both of these techniques require good models relating inputs, measured variables (outputs), and unmeasured variables. Thus there is currently strong emphasis on process identification and on-line parameter estimation as well as new methods of state estimation.

4. Control System Design for Highly Sensitive Processes Having Limited Controller Power.

In the process industries, there are a number of strongly nonlinear processes, such as chemical reactors, which exhibit ignition/extinction phenomena, nonlinear oscillations, and other unstable types of behavior. These often have limited controller power (e.g., finite cooling capacity) and can sometimes operate under conditions where simple feedback control is inadequate to prevent unwanted or even catastrophic process behavior. There is a need to develop control system designs which account for such sudden changes in dynamic behavior and optimize performance close to controller power constraints.

5. Control System Design for Distributed Parameter Processes.

Processes such as packed columns for mass transfer operations or tubular reactors are distributed in space. Thus the controller design involves choosing the optimal placement of sensors (e.g., thermocouples and composition probes) and the best location of actuators (e.g., feed injection or intermediate heat exchange). Thus distributed parameter systems theory must be used as a guide in order to have the highest quality and most robust controller design.

Recent Research Developments

In this section we shall briefly describe areas of current fundamental research activity and provide recent key references in each area.

Linear Multivariable Control

This field has an enormous literature including several recent books (e.g., MacFarlane, 1980) and even a special issue of IEEE Transactions in February 1981.

The question of selection of loop pairings has received considerable attention recently with focus on dynamic measures of interaction. Jerome (1982) and Jensen, Fisher, and Shah (1982) have prepared critiques of proposed methods and find serious failings with all the simple criteria especially in detecting one-way interactions. Both papers conclude that the only completely reliable methods are computer based involving interactive graphics (such as the Direct Nyquist Array). Fortunately many CAD packages exist for this analysis (see below).

The overriding problem with interacting multivariable systems is controller tuning and compensator design. This involves an optimal tradeoff between good performance (high controller gains and sensitivity to parameter variations) and control system robustness (low controller gains and sluggish response). These considerations are disturbance frequency dependent and require a systematic approach for solution. Doyle and Stein (1981) provide a good description of the relevant issues. In particular they provide a good description of the use of singular values (also known as principal gains, spectral norms) of a linear system in order to measure stability margins and performance just as the amplitude ratio is used for single input - single output systems. As indicated in Table 2, a number of other authors have recently addressed the issue of high performance, robust multivariable control.

Many multivariable processes which arise in practice have significant time delays. These arise naturally in simplified models, as a result of transport delays, or because of chemical analysis delays.

Adaptive Control

In order to deal with temporal variations in process dynamic characteristics, adaptive control techniques have been developed. Most of these involve updated model identification at certain intervals and include schemes for modifying controller parameters based on the most recent model. A very general structure is shown in Fig. 3. Note that the process identification scheme estimates certain parameters θ which are used to adaptively modify the controller parameters k. The various adaptive control schemes differ in the manner in which process identification and adaptation are carried out. Several recent books and conference proceedings are devoted entirely to these methods (Landau, 1979; Narenda (1979, 1981)).

Distributed Parameter Systems

An important class of dynamic systems encountered in process control are those processes distributed in space as well as evolving in time. The time domain representations for these systems usually take the form of partial differential equations or integral equations while the frequency domain descriptions result in transcendental transfer functions. The control problem is further complicated by a choice of spatial location for the actuators (e.g., should these be placed at the boundaries or at specific zones or locations in the spatial domain). In addition, sensor locations must be chosen to provide the most relevant information to the controller. An important practical situation where this arises is in packed bed reactor control where one must choose the location for actuators (e.g., heat exchange and mid-bed injections of feed) as well as sensors (e.g. temperature, pressure, and composition sensors in the bed). Several recent books and proceedings (Ray and Lainiotis, 1978; Ray, 1981c; IFAC (1971, 1977, 1982) provide a good overview of the recent state of the field. As indicated in the Survey of Applications by Ray (1978), distributed parameter systems theory finds process control applications for packed bed reaction and mass transfer operation, heat exchangers, solids heating in furnaces and kilns, casting operations, tubular reactors of all types, and underground oil recovery.

CAD of Control Systems

Computer-aided-design (CAD) of control systems is a rapidly growing new development both in industry and at universities around the world. Although, rather substantial control systems design packages have been available in England (Rosenbrock, MacFarlane and coworkers) for a decade or more, until recently these techniques were not in widespread use. However, with the coming of cheap, user-friendly, high performance computer systems, a large number of CAD packages now exist around the world. At a recent Engineering Foundation Conference in the USA, three state-of-the-art reviews were presented which outline these developments throughout the world (Hashimoto and Takamatsu, 1981; Tysso, 1981a; Edgar, 1981). These together with a recent survey (Lemmens and van den Boom, 1979) and an IFAC

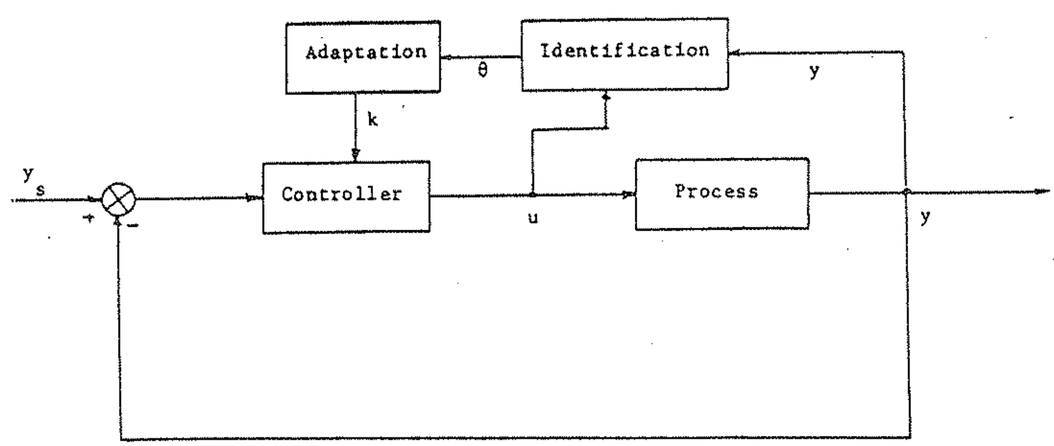

Figure 3. General Structure of an adaptive controller

TABLE 2
Computer Aided Control System Design

Rosenbrock (1969)	Edgar (1981)
MacFarland and Belletrutti (1973)	Furuta and coworkers (1981)
Becker and coworkers (1979)	Harvey and Wall (1981)
IFAC (1979)	Hashimoto and Takamatsu (1981)
Lemmens and van den Boom (1979)	Polak (1981)
Jensen and coworkers (1980,1981)	Tysso (1981)
Astrom and Elmquist (1981)	Chang and Seborg (1981)
Balchen and Tysso (1981)	Ogunnaike and Ray (1982)

Symposia (IFAC, 1979) describe the situation through 1980.

In an effort to determine the extent of CAD in control system development in the U.S. process industries, Edgar (1981) conducted a survey in 1980. Based on this data, it seems that the extent of application of multivariable process control techniques in U.S. industry seems to lag behind Japan. Although the U.S. respondents reported genuine full scale plant applications of modern multivariable control and estimation methods to an array of processes (cf. Table 3), few of these are documented in the open literature. Furthermore, less than 10% of the industrial respondents reported any experience with general purpose CAD packages for control system design. However, all signs point to a much greater utilization of these methods by U.S. industry.

Conclusions

At the present time multivariable process control is a very dynamic and exciting field. There is a large reservoir of basic theory which is being refined to practice through simulation and pilot scale testing. Unifying approaches to control system design are being developed and made easy to implement through interactive, graphical, computer-aided design programs. The lack of good dynamic models (which has hindered model-based control strategies in the past) is being addressed by new techniques which provide for process identification as part of the overall strategy. Considerable real time computing power and sophisticated multicolor graphics are now routinely provided with each new process and are being retrofitted to older plants; thus high performance control systems of the future will principally depend on new reliable sensor development and imaginative, easy to tune, controller design strategies. Today, as at no time in the recent past, real progress in this field depends on our imagination in devising high quality and robust control schemes. We should plan to allocate the financial and human resources to meet this challenge.

TABLE 3
Some Reports Applications of Modern Process Control Techniques in U.S. Industry (Edgar, 1981)

six stand hot rolling gauge control	pH control for wastewater neutralization
continuous casting metal level control	boiler control (steam and gas turbines)
slab temperature control	process heat solar collector
paper machine control	hydrocracker temperature control
rubber calender control	chemical reactor control
ammonia plant	distillation column control
biological wastewater treatment	

References

Astrom, K.J., and H. Elmqvist (1981). Perspective on interactive software for computer aided modeling and design of control systems. 1981 IEEE Decision and Control Conference, 402.

Balchen, J.G. and A. Tysso (1981). Application of CAD in modelling, identification, and control of industrial and large scale nontechnical processes. Proceedings of IEEE Decision and Control Conference, p. 429

Becker, R.G., A. J. Heunis, D.O. Mayne (1979). Computer-aided design of control systems via optimisation. Proc. IEE, 126, 35.

Bennett, S. (1974). A History of Control Engineering, 1800-1930. Inst. Elec. Engrs., London.

Bode, H.W. (1945). Network Analysis and Feedback Amplifier Design. Van Nostrand, Princeton.

Chang, T.S., and D.E. Seborg (1981). A linear programming approach for multivariable feedback control with inequality constraints. 1981 IEEE Decision and Control Conference, 426.

Christensen, J.H., P.M. Vargo (1971). A facility for education in real time computing. Chem. Eng. Edu., 5, 30.

Douglas, J.M. (1972). Process Dynamics and Control. Prentice-Hall, Vol. I, II.

Doyle, J.C., and G. Stein (1981). Multivariable feedback design: concepts for a classical/modern synthesis. IEEE Trans. Auto. Control, AC-26, 4.

Eckman, D.P. (1945). Principles of Industrial Process Control. Wiley.

Edgar, T.F. (1981). New results and status of computer-aided process control system design in North America. Proceedings Chemical Process Control II, p. 213

Eykhoff, P. (1974). System Identification. Wiley, New York.

Fisher, D.G. (1971). Real time computing in the university. Chem. Eng. Edu. 5, 24.

Fuller, A.T. (1976). The early development of control theory. J. Dynamic Systems, Measurement and Control, Trans. ASME, 98G, 109, 224.

Furuta, K., S. Hatakeyama, and H. Kominami (1981). Structural identification and software package for linear multivariable systems. Automatica, 17, 755.

Gould, L.A. (1969). Chemical Process Control. Addison-Wesley.

Harvey, C.A., and J.E. Wall (1981). Phases in the development of control system design software. 1981 IEEE Decision and Control Conference, 420.

Hashimoto, I., and T. Takamatsu (1981). New results and status of computer-aided process control systems designed in Japan. Proceedings Chemical Process Control II, edited by Seborg and Edgar, p. 148.

Hougen, O.A. (1977). Seven decades of chemical engineering. CEP, 73(1), 89.

IFAC Symposium on Computer-Aided Design of Control Systems (1979). Pergamon Press, Zurich.

Proceedings IFAC Symposia on Control of Distributed Parameter Systems. (1971, Banff), (1977, Warwick), (1982, Toulouse). Pergamon Press.

Jazwinski, A.H. (1970). Stochastic Processes and Filtering Theory. Academic Press, New York.

Jensen, N., D.G. Fisher, and S.L. Shah (1980). Comment on a 'note on the extension of Rosenbrock's Nyquist array techniques to a larger class of transfer function matrices'. Int. J. Cont., 32, 737

Jensen, N., D.G. Fisher, and S.L. Shah (1982). Interaction analysis in multivariable control system design. AIChE J. (in press).

Jensen, N., D.G. Fisher, S.L. Shah, and J.F. Kuan (1981). Development and application of a practical multivariable frequency response domain design procedure. Research Rept. 810301, Dept. of Chemical Engineering, University of Alberta.

Jerome, N. (1982). Multivariable Control. MSc Thesis, U. Wisconsin.

Koppel, L.B. (1968). Introduction to Control Theory with Applications to Process Control. Prentice-Hall

Landau, I.D. (1979). Adaptive Control, The Model Reference Approach. Marcel Dekker, New York.

Lapidus, L., and R. Luus (1967). Optimal Control of Engineering Processes. Ginn-Blaisdel.

Lemmens, W.J.M., and A.J.W. van den Boom (1979). Interactive computer program for education and research. Automatica, 15, 113.

MacFarlane, A.G.J. (1980). Complex variable design methods. In Modern Approaches to Control System Design, N. Munro, ed., Peter Peregrinus Ltd., pp.101-137.

MacFarlane, A.G.J., and J.J. Belletutti (1973). The characteristic locus design method. Automatica, 9, 575

Martin-Sanchez, J.M. (1980). Adaptive-predictive control system. U.S. Patent 4,197,576.

Mayr, O. (1970). Origins of Feedback Control. MIT Press, Cambridge.

Morari, M. (1981). Integrated plant control: A solution at hand or a research topic for the next decade. Proceedings Chemical Process Control II, edit. by Seborg and Edgar, p. 467.

Morari, M., and W.H. Ray (1979). Integration of real time computing into process control teaching. Chem. Eng. Edu., 13(4).

Morari, M., and W.H. Ray (1980). Integration of real time computing into process control teaching. Chem. Eng. Edu., 14(1)

Narendra, K.S. (1979) (edit.). Proceedings of Workshop on Applications of Adaptive Control. Yale University..

Narendra, K.S. (1981) (edit.). Proceedings of Workshop on Applications of Adaptive Control. Yale University.

Nyquist, H. (1932). Regeneration theory. Bell Syst. Tech. J., 11, 126.

Ogunnaike, B.A., and W.H. Ray (1982a). Computer-aided multivariable control system design for processes with time delays. Computers and Chem. Eng., in press.

Polak, E. (1981). Interactive software for computer aided design of control systems via optimization. 1981 IEEE Decision and Control Conference, 408.

Ray, W.H. (1978). Some recent applications of distributed parameter systems theory - A survey. Automatica, 14, 281.

Ray, W.H. (1981a). Process control - practice, research, and education. Chem Tech, II, p. 300.

Ray, W.H. (1981b). New approaches to the dynamics of nonlinear systems with implications for process and control system design Proceedings Chemical Process Control II, edit. by Seborg and Edgar, p. 246.

Ray, W.H. (1981c). Advanced Process Control. McGraw-Hill, New York.

Ray, W.H., (1982). Multivariable Process Control-A Survey. Proceedings International Symposium on Process Systems Engineering.

Ray, W.H., and D.G. Lainiotis (1978) (ed). Distributed Parameter Systems. Marcel-Dekker, New York.

Rosenbrock, H.H. (1969). Design of multivariable control systems using the inverse Nyquist array. Proc. IEE, 116, 1929.

Rosenbrock, H.H. (1974). Computer-Aided Control System Design. Academic Press, London.

Seborg, D.E. (1980). Survey of process control education in the U.S. and Canada. Chem. Eng. Edu., 14(1).

Sorenson, H.W. (1980). Parameter Estimation. Marcel Dekker, New York.

Tysso, A. (1981). New results and status of computer-aided process control system design in Europe. Proceedings Chemical Process Control II, p. 187.

Westerberg, A.W., and R.C. Eschenbacher (1971). A real time computer control facility at the University of Florida. Chem. Eng. Edu., 5, 32.

Ziegler, J.G., and N.B. Nichols (1942). Optimum settings for automatic controllers. Trans. ASME, 64, 759.

A REVIEW OF ADVANCED CONTROL STRATEGIES

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Control and Modeling Philosophies

The output or state feedback approach is still the most accepted controller structure, whether for analog or digital models or for single input-single output (SISO) or multiple input-multiple output (MIMO) processes. Feedback control design techniques can be classified under the following general headings:

1) frequency domain (open or closed loop frequency response)
2) root locus, where closed loop eigenvalues and sometimes eigenvectors can be specified
3) optimal control, where a performance function is optimized (e.g., minimum variance)

Special considerations, such as dead time compensation, can be discussed under the three areas.
The goal of the above techniques is to achieve the following desirable controller characteristics:

1) adequate disturbance rejection
2) quick response to set point changes
3) insensitive to model and measurement errors
4) avoids controller saturation or excessive control action
5) requires minimum process information
6) stable in the face of instrument failure
7) suitable over a wide range of operating conditions

While it may be impossible to achieve all of these goals simultaneously, it is clear that a "super-controller" which is inexpensive to implement and always achieves superior performance is the paragon against which all controllers must be measured. This has led to a design approach which is often based on interactive graphics, allowing successive evaluation of many alternatives.
One preliminary consideration in controller design is how the selection of the model affects the nature of the controller. Use of modern (multivariable) control theory usually requires better models, often more detailed than first or second order plus dead time. These models may be based on a fairly rigorous interpretation of physical and chemical principles. Using distributed physical or chemical measurements for state feedback is certainly appealing. However, for large scale systems (such as a distillation column or a multi-unit system) the use of physical models is less attractive, due to the large amounts of manpower and time required in model development (for the example of modeling a distillation column, see ref. (9) and (10)). Therefore for these systems the so-called black box models are favored for most "on-line" applications. That is not to say that physical models do not lend insight into synthesis of the control structure as well as provide a tool for simulation; these are perhaps the most valuable roles for physical models.

In the literature there have been significant efforts in physical modeling and controller design for the following multivariable unit operations (Rijnsdorp and Seborg (11)):

1) distillation columns - Buckley (12), Edgar and Schwanke (9).
2) reactors-Padmanabhanan and Lapidus (13), Wallman and Foss (14).
3) fluid catalytic crackers - Kurihara (15), Schuldt and Smith (16).
4) Wastewater treatment - Olsson (17).

5) paper processing - Church (18).
6) furnaces - Clelland (19).
7) double effect evaporator - Fisher and Seborg (20).

All design methods to be discussed in this section are for linear dynamic systems. Such systems can be described in the time domain by the state space regulation equation

$$\dot{x} = \underline{A}x + \underline{B}u + \underline{F}d \quad (1)$$

$$y = \underline{C}x \quad (2)$$

x,u and d are vectors which represent deviations from a selected steady state operating point, x represents the state vector of dimension n, the definition of n state variables is necessary for complete specification of the dynamic system. The inputs in equation (1) are the control vector u, of dimension r, and the disturbance vector, d of dimension p.

The output vector, y, is of dimension m, which represents the linear combination of the states which are directly measurable. With state variable notation, one can achieve dynamic compensation through linear feedback (proportional) control and by using augmentation of the state vector. This is a necessary step in allowing for integral control with time domain design methods. Feedback control can be implemented either in terms of $\underline{x}$ (state variable feedback) or $\underline{y}$ (output feedback).

An equivalent description of equations (1) and (2) in terms of multivariable transfer functions (Laplace domain) can also be given:

$$y(s) = \underline{G}(s)u(s) + \underline{G}^*(s)d(s) \quad (3)$$

$$G(s) = \underline{C}(s\underline{I} - A)^{-1}\underline{B}$$

$$\underline{G}^*(s) = \underline{C}(s\underline{I} - \underline{A})^{-1}\underline{F} \quad (4)$$

The poles for $\underline{G}(s)$ are equivalent to the eigenvalues of $\underline{A}$ in equation (1). The output feedback controller in the s domain becomes $u(s) = \underline{K}(s)\ y(s)$.

The closed loop transfer function for set point changes (servomechanism) is

$$y(s) = \{\underline{I} + \underline{G}(s)\underline{K}(s)\}^{-1}\ \underline{G}(s)\ \underline{K}(s)\ r(s) \quad (5)$$

For a fairly complete review of linear multivariable controller design techniques, the reader is referred to articles by MacFarlane (21) and Edgar (22).

Frequency Domain Design Techniques.

The design of SISO systems based on frequency response characteristics includes such well-established methods as the Bode plot and the Nyquist and inverse Nyquist diagrams. During the past ten years there has been a serious effort to extend these methods to treat MIMO systems. In fact, there are several graphics-based software packages developed in Great Britain which are now being marketed commercially. (23), (24). These are generally based on Laplace transform representation of process dynamics and control. The two pioneers who must be credited with leading these developments are H.H. Rosenbrock and A.G.J. MacFarlane.

Decoupling, or non-interacting control, is the oldest multivariable control technique (21). The general philosophy of non-interacting control is to cancel the interactions by choosing a controller of appropriate structure. If $(\underline{G}(s) \cdot \underline{K}(s))$ in equation (5) can be made a diagonal matrix by properly selecting $\underline{K}(s)$, then the product matrix has no interactions (off-diagonal terms are zero). Thus the controller synthesis problem reduces to treating each diagonal element separately as in the single loop problem. In other words, in the decoupled system, r_i only affects y_i but r_i does not affect y_j $(i \neq j)$. In order to obtain a straightforward design problem, controller performance is sacrificed. The loop decoupling approach also can suffer from extreme sensitivity to model errors (if a parameter changes, the design is no longer non-interacting). Pathological cases arise in decoupling when deadtime or positive zeroes occur in the transfer function matrix. In the former case, a controller with a "prediction" element $(e^{\Theta s})$ may arise, while in the latter case the controller will contain an unstable element (21). Another disadvantage of exact decoupling is controller complexity.

Experimental applications of decoupling have been popular for distillation columns, as reviewed by Edgar & Schwanke (9).

There are several less binding options available for decoupling. One is to use approximations (sometimes ad hoc) to the required decoupling controllers, often simplifying the controller forms. A second approach is to use partial ("one-way") decoupling. This approach recognizes that one loop may be more sensitive to input-output interactions than another; partial decoupling is implemented by setting one cross-controller (K_{ij}, i=j) equal to zero (Shinskey, (25)). Partial decoupling is more tolerant of model errors. Recent studies by McAvoy and coworkers (26),(27) and Toijala and Fagervik (28) have examined the effects of model errors in decoupling in distillation column models, explaining some difficulties which have been reported for experimental application of decoupling. A still simpler approach is static decoupling, where the dynamics of each element in the transfer function matrix are neglected in the cross-controllers; only the steady state gains are utilized.

Root Locus Techniques. The discussion of root locus methods is almost a standard feature in most undergraduate textbooks, although this procedure is generally acknowledged to be inferior to frequency response methods. It is normally expected that if the closed loop eigenvalues are shifted further to the left in the complex plane, the system will be faster responding. However, this is not always the case. The key problem with root locus or pole placement methods is that they ignore the effects of control on the system eigenvectors.

The primary interest in the pole placement literature recently has been in finding an analytical solution for the feedback matrix so that the closed loop system has a set of prescribed eigenvalues. In this context pole placement is often regarded as a simpler alternative than optimal control or frequency response methods. For a single control (r=1), the pole placement problem yields an analytical solution for full state feedback (e.g., (29),(30)). The more difficult case of output feedback pole placement for MIMO systems has not yet been fully solved (31).

In the past few years, a number of workable pole-placement algorithms have been published. However, their application to MIMO systems with incomplete state variable feedback are often unsatisfactory in that:

1) Only a limited number of poles can be placed arbitrarily
2) Nothing can be said about the remaining unassigned eigenvalues, i.e., their stability is not guaranteed.
3) For complete pole placement, it is usually required that $r+m \geq n+1$, thus the total number of inputs and outputs are considerably larger than the minimum condition $r \times m \geq n$. Here the minimum condition means that when $r \times m \geq n$, it is likely that a solution exists for the resulting set of nonlinear equations.
4) Usually the algorithm returns a feedback matrix with very large components. This may be unacceptable for a control system with constrained inputs. Finding a feedback matrix with smaller entries by trial and error can be very tedious.
5) The closed loop response depends not only on the closed loop eigenvalues but also on eigenvectors. Intuitive specification of closed loop eigenvalues may be difficult.
6) Time delays are not readily treated.

On-Line Optimization and Control

The design of optimization and control schemes for systems described by linear differential equations with constant coefficients has evolved to a satisfactory level for reasonably sized models. Many techniques are available, giving a control engineer much flexibility in the choice of techniques. However, the chief failing in this type of control/optimization structure is the assumption that the parameters of the process remain constant. In most actual processes, the parameters are either poorly known (usually due to measurement and/or modeling deficiencies) or are time-varying in nature. One solution to this problem is to design a worst case controller; however, this solution is definitely inferior to an adaptive controller, where on-line state and parameter identification of the process is incorporated into the controller action. A "gain-adaptive" controller is presently commercially available, but this is only a first step towards more powerful adaptive control methods which could be implemented in industry.

An adaptive controller normally will incorporate the highly successful feedback structure. In the field of adaptive control, three general approaches have been developed (32):

(1) design an "insensitive" or robust controller
(2) adjust the controller parameters in response to output performance characteristics
(3) measure on-line the plant parameters and adjust the control law based on prior analysis

The first two approaches appear to be the most suitable for chemical process applications; the robust controller is particularly attractive for microprocessor-based control. The second approach is usually superior to the third because parameter measurement delays can negate the adaptive control advantages.

The development of an insensitive controller can of course be accomplished by repetitive simulations, but this by itself is an inefficient and usually impractical approach. The design of such a controller using standard linear optimal control methods has not proven to be fruitful as yet, since inclusion of sensitivity measures in the performance index does not yield to a closed form solution (33),(34). There is a need for improved methods which can realize desired sensitivity characteristics as well as high performance without resorting to extensive interactive calculations; Davison (35) has recently suggested one such approach.

Other recent developments in the field of adaptive control of interest to the processing industries include the use of pattern recognition in lieu of explicit models (Bristol (36)), parameter estimation with closed-loop operating data (37), model algorithmic control (38), and dynamic matrix control (39). It is clear that discrete-time adaptive control (vs. continuous time systems) offers many exciting possibilities for new theoretical and practical contributions to system identification and control.

Control with Limited Measurements

One of the major questions in control system design is the selection of process measurements. An important deficiency of state variable control is that measurements or estimates of all state variables are required. Usually only a few of the states can be monitored instantaneously, because of sensor cost or time delays caused by the need for chemical analysis. Distillation columns with many components and large numbers of trays would create special difficulties. The multivariable frequency domain methods require output information only; linear optimal control, on the other hand, does require complete state measurement or state estimates. Observer theory or filtering theory can be used to provide estimates of the unmeasured state variables from input/output data. These estimates can then be used with the computed optimal control law; the combination of the Kalman-Bucy filter with the optimal feedback matrix is optimal for the stochastic LQP. The filter approach reduces the phase advance and reduces the system sensitivity to high frequency noise, but at the expense of extra on-line computation and system performance. An observer has the opposite effect, increasing phase advance of the system even more.

An approach called inferential control has been developed by Brosilow and coworkers (40),(41) to address the measurement limitation problem, especially when unmeasured disturbances are present. The disturbances, when persistent, are problematic for the Kalman filter approach. Weber and Brosilow (40), in their research with distillation columns, have developed a static estimator which predicts the product quality based on readily available measurements; measurements can be selected so that the estimator is relatively insensitive to modeling errors and measurement noise. Their approach also avoids the need for observers or dynamic state estimators. The inferential control approach has an extra advantage in that composition measurement loop and sampling delays can be eliminated. The net result is a tremendous reduction in number of state variables and measurements (although not necessarily yielding a single input-single output coupling). The number of measurements is selected so the control system is insensitive to modeling errors. The control system uses the inferred measurements to adjust the control effort and counteract the unmeasurable disturbances. A dynamic compensation scheme for the static estimator/controller based on simple lead-lag elements has been developed by Brosilow and Tong (41).

A related idea in process control which has received much interest recently is the analysis of interactions among states, outputs, and controls. The analytical technique used in many commercial applications is the relative gain array (Bristol, (42)). Rather than being explicitly based on system dynamics, it yields a measure of the steady state gain between a given input/output pairing. By using the most sensitive SISO connections, control magnitudes can be minimized. The relative gain array can be obtained analytically, computationally, or experimentally, and the basis for computing the relative gain matrix, of dimension mxm (m = number of outputs and the number of controls) is

$$\phi_{ij} = \left.\frac{dy_i}{du_j}\right|_{u_{i \neq j}} \tag{6}$$

ϕ_{ij} is a measure of the sensitivity of output i to controller j; it is computed by varying the jth controller output while holding all other controller outputs constant. Interaction is quantitatively measured by

$$\mu_{ij} = \underline{\phi} \cdot \left(\underline{\phi}^t\right)^{-1} \tag{7}$$

As shown by Bristol (42) for controllers with heavy reset action, this measure has very interesting properties. Input/output pairs are selected for those μ_{ij} approaching 1. A negative element in μ_{ij} indicates instability or non-minimum phase behavior.

McAvoy (43) has explored the use of this index and a dynamic version of the index to analyze two-point composition control in distillation columns. Input-output pairing using equation (7) can often lead to poor control, while the opposite pairings can actually yield better results. This is especially true for time delay and non-minimum phase processes. Tung and Edgar (44) have developed a comprehensive theory of control-output dynamic interactions for linear systems which includes the steady state relative gain index as a special case. They have applied this dynamic interaction index to analysis of a distillation column and a fluid catalytic cracker. Gagnepain and Seborg (45) have also proposed an interaction measure based on open loop step responses and have provided some interesting comparisons with McAvoy's results. The subject of the interaction index employed as a process design tool is also addressed in the following section.

Integration of System Design and Control Considerations

In the practice of engineering the synthesis of control systems is normally performed after the system design, i.e., after selection of steady state parameters is completed.

Thus a system which may appear attractive based on steady state analysis may have very undesirable dynamic properties, making successful control system design a difficult task. When energy costs were low, the decoupling of the design and control steps usually did not lead to uncontrollable systems; however, with increasing fuel prices, energy integration has been introduced to greater degrees in order to reduce energy requirements, and the design and control steps have become more strongly related.

The problem of satisfying both steady state and dynamic objectives transcends the problem of control of individual processes. Design procedures for single pieces of equipment are well-established, although for reasonably complicated processes (such as reactors and distillation columns), there are still some questions to be resolved. The more challenging research problems fall under the heading of plant control, where several units are integrated, for example, to conserve energy. Simple decomposition of the overall process into discrete blocks is usually very difficult.

In heat recovery applications there can be a large number of feasible plant configurations. After the configuration is optimized based on steady state considerations (which may not be an easy problem), the evaluation of the effectiveness of various control schemes can be performed. The dynamic plant operation must be evaluated in terms of economics, regulation, reliability, and safety over a broad range of operating regimes.

On the other hand, the control evaluation could be performed in tandem with the design study, thus ruling out candidate design configurations rather early because of control difficulties. It would be advantageous to have quick and uncomplicated screening methods to evaluate potential control structures in the design phase; alternatively, the control structure optimization could be incorporated as part of the steady state design optimization. This would avoid the necessity of actual controller synthesis, which is obviously unattractive and could be quite time-consuming.

One approach for control evaluation discussed earlier is the relative gain array (42),(44). No actual synthesis of the controller is required in these algorithms. The development of such screening tools is still in its infancy but appears to be quite promising for concurrent design/control evaluation. Such techniques, if simple to use, would be immediately acceptable for use by major engineering firms and the process industries.

The overall plant control concept and incorporation of more detailed control design with plant design requires the selection of the following elements:

(1) control objectives
(2) output variables
(3) measurements
(4) manipulated variables
(5) control structure

There are a number of available techniques for evaluating the control system, which can be classified as follows:

(1) analysis of control constraints (rather than dynamics)(46)
(2) generating alternative control structures for each unit and minimizing conflicts among the various structures, using a multilevel analytical approach (47)
(3) satisfying product quality and controlling the material balance as primary objectives (steady state control), followed by dynamic analysis (48),(49)
(4) aggregation of units that have common functional goals in terms of control and economics (50)

While these techniques have been applied to energy-related processes such as heat-integrated distillation columns and fluid catalytic cracking reactors, there is still extensive research required before the concept of plant design/control is reduced to practice.

The operation of energy-integrated plants will make it necessary to design control systems which are decentralized but which also respond to overall plant objectives. Existing modern control theory is really not adequate for these large scale problems, since there may be over 50 state variables. These systems are often made up of interconnected and often similar elements and must be controlled by an hierarchy of computers - micro, mini, and macro. The questions of system structure, representation, and modeling and control, measurement, and optimization strategies are fertile ones. An issue of the IEEE Transactions on Automatic Control (April, 1978) was devoted entirely to this subject. There have been only a few applications of multilevel or distributed control reported in the literature (51),(52),(53), but during the next decade this area promises to be one of great activity.

References

1. Foss, A.S.; and Denn, M.M., Ed., "Chemical Process Control," AIChE Symp. Ser., 1976, 72, No. 159.
2. Edgar, T.F.; and Seborg, D.E., Ed., "Chemical Process Control II," Engineering Foundation Publications, P-33, 1981
3. Coughanowr, D.R.; and Koppel, L.B., Process Systems Analysis and Control, McGraw-Hill, New York, 1965.
4. Edgar, T.F., "Assessment of the Use of Process Dynamics and Control for Influencing Energy Utilization in Industrial Processes, paper presented at Department of Energy Workshop on Process Dynamics and Control, Denver, Colorado, June, 1979.
5. Robnett, J.D., "Engineering Approaches to Energy Conservation," Chem. Engr. Prog., 1979, 75 (3), 59.
6. Kenney, W.F., "Reducing the Energy Demand of Separation Processes," Chem. Engr. Prog., 1979, 75 (3), 68.
7. Smith, O.J.M., "Closer Control of Loops with Dead Time," Chem. Engr. Prog., 1957, 53, 217.
8. Smith, C.L., Digital Computer Process Control, In text, Scranton, Pa., 1972.
9. Edgar, T.F.; and Schwanke, C.O., "A Review of the Application of Modern Control Theory to Distillation Columns, "Proc. Joint Automatic Control Conference, 1977, 1370.
10. Tung, L.S.; and Edgar, T.F., "Development and Reduction of a Multivariable Distillation Column Model with Tray Hydraulics," AIChE National Meeting, Houston, Texas, April, 1979.
11. Rijnsdorp, J.E.; and Seborg, D.E., "A Survey of Experimental Applications of Multivariable Control to Process Control Problems," AIChE Symp. Ser., 1976, 72 (159), 112.
12. Buckley, P.B., "Distillation Column Design Using Multivariable Control," Inst. Tech., 1978, 25(3), 115.
13. Padmanabhan, L.; and Lapidus, L., "Control of Chemical Reactors" in Chemical Reactor Theory: A Review, Ed. by L. Lapidus and N.R. Amundson, Prentice-Hall, Englewood Cliffs, N.J., 1977.
14. Wallman, P.H.; and Foss, A.S., "Multivariable Integral Controls for Fixed Bed Reactors," AIChE Annual Meeting, Miami, Florida, November, 1978.
15. Kurihara, H., Optimal Control of Fluid Catalytic Cracker, Report ESL-R-309, M.I.T., June, 1967.
16. Schuldt, S.B.; and Smith, F.B., "An Application of Quadratic Performance Synthesis Techniques to a Fluid Catalytic Cracker," Proc. Joint Automatic Control Conference, 1971, 270.
17. Olsson, G., "State of the Art in Sewage Treatment Plant Control, "AIChE Symp. Ser., 1976, 72 (159), 52.
18. Church, D.F., "Cement and Projected Pulp and Paper Industry Problems in Process Control and Process Modeling," AIChE Symp. Ser., 1976, 72 (159), 19.
19. Clelland, P.J., "Recent Furnace Draft Control Considerations," Proc. IEEE Conf. on Dec. and Cont., 1977, 1101.
20. Fisher, D.G.; and Seborg, D.E., Multivariable Computer Control-A Case Study, North-Holland Publishing Co., Amsterdam, 1976.

21. MacFarlane, A.G.J., "A Survey of Some Recent Results in Linear Multivariable Feedback Theory," Automatica, 1972, 8, 455.
22. Edgar, T.F., "Status of Design Methods for Multivariable Control," AIChE Symp. Ser., 1976, 72, (159) 99.
23. Munro, N.; Broland, B.J.; and Brown, L.S., "The UMIST Computer-Aided Control System Design Suite," National Research Development Corporation, Great Britain, 1973.
24. Rosenbrock, H.H., Computer-Aided Control System Design, Academic Press, New York, 1974.
25. Shinskey, F.G., "The Stability of Interacting Control Loops with and without Decoupling," Proc. Fourth IFAC Multivariable Technological Systems Conference, 1977, 21.
26. Jafarey, A.; and McAvoy, T.J., "Degeneracy of Decoupling in Distillation Columns," IECPDD, 1978, 17, 485.
27. McAvoy, T.J., "Steady State Decoupling Sensitivity with Application to Distillation Control," AIChE National Meeting Houston, Texas, April, 1979.
28. Toijala (Waller),K.V.; and Fagervik, K.C., "A Digital Simulation Study of Two Point Feedback Control of Distillation Columns," Kem. Teollisuus, 1972, 29, 5.
29. Simon, J.D., and Mitter, S.K., "A Theory of Model Control," Inf. Control, 1968, 13, 316.
30. Davison, E., "On Pole Placement in Linear Systems with Incomplete State Feedback," IEEE Trans. Auto. Cont., 1970, AC-15, 348.
31. Vardulakis, A.I., "Generalized Root Locus Assignment of All Poles of a Multivariable System by Output Feedback," Int. J. Cont., 1976, 23, 39.
32. Landau, Y.D., Adaptive Control, Marcel Dekker, New York, 1978.
33. Newman, M.M., "On Attempts to Reduce the Sensitivity of the Optimal Linear Regulator to a Parameter Change,", Int. J. Cont., 1970, 11, 1079.
34. Sannuti, P.; and Cruz, J.B., "A Note on Trajectory Sensitivity of Optimal Control Systems," IEEE Trans. Auto. Cont., 1968, AC-13, 111.
35. Davison, E.J., "Decentralized Robust Control of Unknown Systems Using Tuning Regulators," IEEE Trans. Auto. Cont., 1978, AC-23, 276.
36. Bristol, E.H., "Pattern Recognition: an Alternative to Parameter Identification in Adaptive Control," Automatica, 1977, 13, 197.
37. Box, G.E.P.; and MacGregor, J.F., "Parameter Estimation with Closed Loop Operating Data," Technometrics, 1976, 18, 371.
38. Richalet, J.; Rault, A.; Testud, J.L.; and Papon, J., "Model Predictive Heuristic Control: Applications to Industrial Processes," Automatica, 1978, 14, 413.
39. Cutler, C.R.; and Ramaker, B.L., "Dynamic Matrix Control-A Computer Control Algorithm," AIChE National Meeting, Houston, Texas, April, 1979.
40. Weber, R.; and Brosilow, C.B., "The Use of Secondary Measurements to Improve Control," AIChE J., 1972, 18, 614.
41. Brosilow, C.B.; and Tong, M., "The Structure and Dynamics of Inferential Control Systems," AIChE J., 1978, 24, 492.
42. Bristol, E.H., "On a New Measure of Interaction for Multivariable Process Control," IEEE Trans. Auto. Cont., 1966, AC-11, 133.
43. McAvoy, T.J., "Interacting Control Systems: Steady State and Dynamic Measurement of Interaction," ISA Trans., 1978, 16, (3), 35.
44. Tung, L.S.; and Edgar, T.F., "Analysis of Control-Output Interactions in Dynamic Systems," AIChE Meeting, Miami, Florida, November, 1978.
45. Gagnepain, J.P.; and Seborg, D.E., "An Analysis of Process Interactions with Applications to Multi-Loop Control System Design," AIChE Annual Meeting, San Francisco, Nov., 1979.

46. Govind, R.; and Powers, G.J., "Synthesis of Process Control Systems," IEEE Trans. Sys. Man. Cyb., 1978, FMC-8, 792.
47. Umeda, T.; and Kuriyama, T., "A Logical Structure for Process Control System Synthesis," Proc. IFAC Congress, Helsinki, Finland, 1978.
48. Buckley, P.S., Techniques of Process Control, Wiley, New York, 1964.
49. Douglas, J.M., "Quick Estimates of Control Economics," AIChE Annual Meeting, New York, 1977.
50. Morari, M.; Arkun, Y.; and Stephanopoulos, G., "An Integrated Approach to the Synthesis of Process Control Structures," Proc. Joint Automatic Control Conference, 1977, 243.
51. Ray, W.H.; and Lainiotis, D.G., Distributed Parameter Systems, Marcel Dekker, New York, 1978.
52. Kociuba, T.; and Ponstingl, J.C., "Energy Management Systems for Industry," Proc. Fouth Annual Advanced Control Conference, Purdue University, April, 1977.
53. Al-Shaikh, A.; and Leffler, N., "Application of Multi-Level Control of Calenders in the Tire Industry," Automatica, 1978, 14, 1.

REVIEW

Exxon Experience with Large Scale Linear and Nonlinear Programming Applications

by J.D. Simon and H.M. Azma, Exxon
Los Angeles meeting paper 23b

Exxon recognized the potential benefits of Linear Programming (LP) during the fifties. Due to limitations in the computer power available at that time LP applications were limited to operations within a single refinery such as product blending. As capabilities have grown, they now involve single plant models, multiplant models within operating regions, and even multi-regional models. Some models incorporate multi-time period structure to account for dynamic nature of a problem.

By 1968, 63 separate LP applications had been developed based on IBM's Math Programming System software coupled with a host of other languages for model generation and reporting. They recognized that to achieve the desired progress they would need:

- A system to keep track of many data items (over 70,000) and permit data sharing between models for consistency.
- A data-driven uniform approach to Matrix Generation to help avoid modeling errors and allow for greater portability of models and staff.
- An open-ended system which would easily permit the introduction of different solution strategies.
- Ability to easily retrieve information related to previous cases.
- Facility to easily obtain both standard and ad hoc reports.
- A simple, powerful language to enable the user to perform all functions from data base management to report generation.

After a survey of available languages, they decided to work with Management Science Systems to develop a new math programming system, MPS III (now a product of Ketron, Inc.). By 1973, a version of MPS III was available which they call PLATOFORM (PLAnning TOol developed in dataFORM).

The models with PLATOFORM are primarily linear with nonlinear relationships added as necessary to achieve accuracy consistent with study objectives. One class of non-linearities arises from blending of non-additive component qualities. In lead addition for octane number improvement, straight linear programming has been usable for many years because the additive's effect follows the law of diminishing returns. When linear constraints are inadequate, then some form of Sequential Linear Programming (SLP) can be invoked. SLP is similar in concept to the Mathematical Approximation Programming (MAP) procedure introduced by Shell in 1961.

A second type of non-linearity problem arises when several intermediate process streams are sent to a holding tank (Pool) and then the material in the tank is used as a blending component. The final product involves multiplication of volume and quality both of which are unknown.

Nonlinear financial relationships, such as economies of scale are often approximated linearly and treated by case study. As a rule of thumb, SLP requires about one third more time than the base LP run.

PLATOFORM employs a branch and bound mixed integer code called BLOODHOUND developed within Exxon. It has available many specialized strategies that can make use of analyst supplied and problem dependent information. They feel that the BLOODHOUND approach gives it about a 10 to 1 performance benefit over general purpose mixed integer codes.

In addition, Exxon has developed solution techniques which are problem dependent. ECO is a Successive Quadratic Programming (SQP) code. This Exxon Computer Optimizer was put in production status in 1969. It was revised in 1970 to handle a gas field optimization which required over 300 variables. It was so successful that a special version was linked to a reservoir simulation system and sold outside of Exxon as ECO-DYNRES.

There are occasional LP applications with over 1000 variables where it is desirable to explore the addition of quadratic terms to the objective function. Their 1970 version was called QUADIT. A new program called CHOP (Convex Hull Optimization Procedure) was developed to solve QP problems with second order convergence. However, the incentive to use CHOP has disappeared as the more general SLP and BLOODHOUND capabilities developed.

Two outside programs were evaluated in a study described by the authors. The programs were Generalized Reduced Gradient Version 2 (GRG2) and Modular In-core Nonlinear Optimization System (MINOS). These programs were compared with ECO and SLP using examples which are representative of potential applications. The objective functions contained linear and quadratic terms plus a small number of more nonlinear terms. There were at most ten nonlinear constraints active at the Solution and analytical derivatives were used. There were seven problems with 5 variables, twelve with 20, six with 100 and four with 250. Two of the six 100's were strictly linear. ECO was not used with the larger problem because it does not utilize sparse matrix representation.

The paper is to be published by Computers and Chemical Engineering in a forthcoming issue covering "The Status of Large Scale Optimization"

REVIEW

Large Scale Mathematical Programming Systems

by John A. Tomlin, Ketron, Inc.
Los Angeles meeting paper 22b

The author defines large scale Mathematical Programming (MP) problems as those a practitioner can barely afford to solve no matter what its structure or size. The simplex method remains at the core of MP and large scale models being solved are largely Linear Programming (LP).

To be considered a Mathematical Programming System (MPS), in addition to an efficient LP algorithm, there must be a large amount of ancilliary software which makes the power available in a reasonably friendly fashion as well as making the solution available in comprehensible form. Many systems include facilities for solving mixed integer problems via branch and bound algorithms.

Modern LP technology is built around the sparsity of real-world problems. Most models have only 4 to 7 non-zero coefficients in each column regardless of model size. The better systems go even further, taking advantage of the fact that most of the non-zero values in the matrix are either +1 or -1.

Many large models contain a large proportion of logically redundant variables and constraints which can be removed by use of "pre-solve" algorithms. A post-solve procedure then is required to restore those variables in the "formal" optimum.

Sparsity is carried to its ultimate conclusion in network algorithms since each arc corresponds to a +1 and a -1 coefficient plus cost and capacity information. Problems with tens of thousands or even millions of arcs have been solved at modest costs. Such logic has recently been integrated into MPS III. In the past, they have been used in a stand-alone mode.

The Generalized Upper Bound (GUB) algorithm has achieved major speed advantages for some classes of models. These are usually production-distribution problems. The X-System from Insight has handled a fixed charge multi-commodity distribution system with up to 6 million total network arcs and 65,000 fixed charges.

Multi-time period models are an active research area because ordinary LP models typically require 2m iterations for a model with m rows whereas multi-time period models typically take 8 to 10 m iterations.

Maintenance of data bases and reporting of results often costs more than the LP optimization proper. Stand-alone matrix generation and reporting languages are widely used. MPSX/370 has its own language based on PL/1. One problem with PL/1 is the difficulty it has in handling typically used naming conventions for LP. The MPS III system uses DATAFORM modules which may be compiled and executed by calls under program control rather than as separate job steps. This capability has turned out to be crucial in efficient implementation of algorithms which use LP recursively.

It is treacherous to estimate solution costs (or even solvability) for large scale mixed integer programming problems. A comparatively simple LP may have discrete requirements imposed which make it extremely difficult to find any integer solution. Otherwise, simple integer requirements may be imbedded in large and tightly constrained LP.

Successive Linear Programming uses a local linearization with appropriate limits for departures of the non-linear variables from their current values. It has been very successful in practice. As a result of many years of extensive usage, many of the techniques for MPS have been standardized and made much easier to use. However, intelligent user involvement is required for data collection, model specification, algorithm exploitation, report specification and management interpretation of results.

This paper is scheduled to be published by Computers and Chemical Engineering in an issue to cover "The Status of Large Scale Optimization.

MEETINGS,MEETINGS,MEETINGS...

o March 16-18, 1983

Simulation Symposium, Tampa, FL. Contact: Victor P. Boyd, U.S. Postal Service, Room 5304, 475 L'Enfant Plaza, Washington, DC 20260, (202) 245-5274

o March 22-24, 1983

ICS83, Symposium on Applications Systems Development, Nurnberg, W. Germany. Contact: H. Wedekind, Univesitat Erlangen-Nurnberg, Lehrstuhl Informatik VI, Martenstrasse 3, D-8520 Erlangen, W. Germany

o March 27-31, 1983

National AIChE Meeting, Houston, TX. Sessions 85-88 & 90-95 (See January CEP)

o April 19-21, 1983

Congress on Computers in ChE, Paris, France. Contact: R. Mas, Societe de Chimie Industrielle, 28 Rue Saint-Dominique, 75007, Paris, France

o April 21-22, 1983

Modeling and Simulation Conf. Pittsburgh, Pa. Contact: William G. Vogt, 348 Benedum Engineering Hall, University of Pittsburgh, PA, 15261

o April 25-27, 1983

ORSA/TIMS Meeting, Chicago, IL Contact: Robert A. Abrams, Dept. of Quantitative Methods, University of Illinois, Box 4348, Chicago, IL 60680

o April 25-28, 1983

RAI Congress Centre, Amsterdam (see page)

o May 8-11, 1983

Pacific ChE Conf. Seoul, S. Korea. (See p. 107 January CEP)

o May 16-19, 1983

National Computer Conference, Anaheim, CA. Contact: AFIPS, 1815 N. Lynn Street, Arlington, VA 22209 (703) 558-3600

o May 17-19, 1983

Tools, Methods, and Languages for Scientific and Engineering Computation, Paris France. Contact: Brian Ford, NAG Central Office, 256 Banbury Road, Oxford OX2 7DE, England

o June 19-24, 1983

Foundations of Computer-Aided Chemical Process Design (FOCAPD), Snowmass, Co. Contact: Vickie S. Jones, CACHE, MEB 3062, University of Utah, Salt Lake City, UH 84112.

o June 1983

Conf. on Decision Support Systems, Boston, MA. Contact: Patricia Van Cleve, P.O. Box 10001, Austin, TX 78766 (512) 345-7948

o June 22-24, 1983

American Control Conf. San Francisco, CA Contact: Harish S. Rao, Systems Control, 1801 Page Mill Road, Palo Alto, CA 94303 (415) 494-1165.

o June 26-29, 1983

ACM-IEEE Design Automation Conf. Miami Beach, FL. Contact: Charles E. Radke, IBM Corp. (302/300-47A), Hopewell Junction, NY 12533 (914) 897-4682.

o July 11-13, 1983

Computer Simulation Conf. Vancouver, BC, Canada. Contact: A. Jack Schiewe, Aerospace Corp. M1/025, P.O. Box 92957, Los Angeles, CA (213) 648-6120.

o July 25-29, 1983

Conf. on System Modelling and Optimization, Copenhagen, Denmark. Contact: P. Thoft- Christensen, Aalborg University Centre, Institute of Building Technology and Structural Engineering, Box 159, DK-9100, Aalborg, Denmark.

o August 15-17, 1983

Conf. on Mathematical Modeling, Zurich, Switzerland. Conact: Xavier J.R. Avula, Engineering Mecanics Dept., University of Missouri-Rolls, MO 65401.

o August 28-31, 1983

AIChE National Meeting/ Solvent Extration Conf. Denver, CO. No CAST Sessions (See January CEP).

o August 29- September 1, 1983

Symposium on Measurement and Control, Athens, Greece.
Contact: S.G. Tzafestas, MECO 83, EE Dept., University of Patras, Greece.

o August 30- September 2, 1983

Symposium on Modeling, Planning Decision, and Control in Energy and Environmental Systems, Athens Greece.
Contact: ibid.

o September 13-26, 1983

Conf. on Systems Science, Wroclaw, Poland. Contact: Jerzy Swiatek, Techanical University of Wroclaw, Institute of Control and Systems Engineering, Janiszewkiego St. 11/17, 50370 Wroclaw, Poland.

o September 19-23, 1983

World Computer Congress, Paris, France. Contact: AFIPS, 1815 N. Lynn Street, Arlington VA 22209 (703) 558-3600.

o October 4-6, 1983

Weightech, St. Louis, MO. Contact: Daniel J. Cockrell, P.O. Box 1483, Brandon, FL 33511 (813) 958-6371

o October 24-26, 1983

ACM83, New York City. Contact: Thomas D'Auria, City of New York, Computer Service Center. III 8th Ave. 11th Floor, New York, NY 10011

o October 30- November 4, 1983

AIChE Annual Meeting Washington, DC. See pp. 158-162, (January CEP).

o January 4-6, 1984

Conf. on System Sciences, Honolulu, HA. Contact: Ralph H. Sprague. Jr., University of Hawaii, 2404 Maile Way, Honolulu, HA, 96822

o March 11-14, 1983

AIChE National Meeting, Atlanta, GA. No CAST Sessions. See p. 162 (January CEP).

o March 26-30, 1984

Symposium on Computer Applications in the Mineral Industries, London. Contact: Conference Office, Institution of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, England.

o May 20-24, 1984

AIChE National Meeting, Anaheim, CA. Contacts: 10a. Bruce A. Finlayson, ChE Dept. University of Washington, Seattle, WA 98195 (206) 543-4483
10b. Alan S. Foss, ChE. Dept., University of California, Berkeley, CA 94720 (415) 642-4526. 10c. G.V. Reklaitis, School of Chemistry, Purdue University, West Lafayette, IN 47907 (317) 494-4089

o June 14-16, 1984

American Control Conference, San Diego, CA. Contact Irven H. Rinard, Halcon SD Group, 2 Park Ave. New York, NY 10016 (212) 688-1222.

o August 19-22, 1984

AIChE National Meeting, Philadelphia, PA. No CAST Sessions.

o November 25-30, 1984

AIChE Annual Meeting, San Francisco, CA. Contact: Area Chairmen for 10a, b,c noted above.

o March 24-27, 1985

AIChE National Meeting, Houston, TX. Contacts: ibid.

o March 31- April 3, 1985

Use of Computers in ChE. Cambridge, England. Contact: Warren Seider, ChE Dept. University of Pennsylvania, Philadelphia, PA, 19104
(215) 898-7953

o June 1985

American Control Conference, Seattle, WA, Contact: Irven Rinard.

o Summer 1985

Chemical Process Control Research Conference. Contact: Manfred Morari, ChE. Dept., University of Wisconsin, Madison, WI, 53706 (608) 263-2923.

o August 25-28, 1985

AIChE National Meeting, Seattle, WA. No CAST Sessions.

o November 9-12, 1985

AIChE Annual Meeting, Chicago, IL. Contact: Area Chairmen.

Foundations of Computer-Aided Process Design (FOCAPD-83)

About the First Conference

The first International Conference on Foundations of Computer-Aided Process Design (FOCAPD) was held on July 6-11, 1980, at New England College, Henniker, New Hampshire. Sponsored by the AIChE, the NSF, and the Engineering Foundation, the Conference brought together 146 participants from industrial and governmental laboratories and universitites of 16 countries to listen to, discuss, and critique 30 papers covering a wide range of topics in computer-aided process design. The proceedings, published in two volumes, are available from AIChE.

About the Second Conference

Plans are complete for the second conference on Fundamentals of Computer-Aided Process Design (FOCAPD-83) to be held June 29-24, 1983, at the Snowmass resort near Aspen in Colorado. The conference is being sponsored by the CAST (Computers and System Technology) Division of AIChE, the National Science Foundation, and CACHE, with the latter being responsible for all arrangements.

FOCAPD-83 Advisory Committee

Chairman: Arthor W. Westerberg
Carnegie-Mellon Univ.
Co-Chairman: Henry H. Chien
Monsanto Company
Committee Members:
Coleman B. Brosilow
Case-Western Reserve Univ.
Brice Carnahan
University of Michigan
Dwight L. Johnston
Shell Development Co.
John M. Prausnitz
Univ. of California, Berkeley
John H. Seinfeld
California Inst. of Tech.
Vern Weekman, Jr.
Mobil Tyco Solar Energy Corp.

Ex-Officio Members (FOCAPD-80 Organizers)
Richard S.H. Mah
Northwestern Univ.
Warren D. Seider
Univ. of Pennsylvania

Registration and Conference Arrangements

J.D. Seader
Univ. of Utah
Vickie S. Jones
Univ. of Utah (801) 581-6915

Location of the Conference

The Conference will be held at Snowmass, Colorado, a spectacular resort located high in the Rockies, just 20 minutes away from Aspen. At Snowmass, the air is clear and the sunshine warm. The mountain valley is lush with aspen trees and wild flowers. Anowmass has many fine shops, a wide variety of restaurants, and a complete grocery store. Recreation facilities include ecology tours, nature walks, hiking, fishing, horseback riding, chairlift rides, whitewater rafting, swimming, tennis, and golf.

Accommodations

Arrangements have been made for single- and double-room lodge accommodations available at the Silver Tree/ Eldorado at $40 per night, double or single occupancy. Thus, the total room cost will be the same whether occupied as a single or double. The rate for more than two persons in a room is $8/extra person (children under 12 stay free in their parents' room). All rooms have two beds and a small refrigerator. A continental breakfast is included in the room rate.

Condominiums are available ranging from studio accommodations with kitchens at $45/night to three-bedroom units. The Aspenwood, Laurelwood, and Timberline condominiums are closest to the meeting center and the Silver Tree/Eldorado, which will be the headquarters for the Conference.

For further information about the Conference, contact:

Vickie S. Jones
Sept. of Chemical Engineering
MEB 3062
University of Utah
Salt Lake City, Utah 84112
(801) 581-6915

(FOCAPD-83) PROGRAM

Keynote Address "Can 'Expert Systems' Solve Technology Problems"

Peter D. Hart, Fairchild Advanced Research and Development

Session I: "Overview and Outlook"
Chairman: Jerry L. Robertson, Exxon
Roger Sargent, Imperial College, "Challenges and Constraints in Computer Science and Technology"
Stanley I. Proctor, Monsanto Company "Challenges and Constraints in Computer Implementation and Applications"

Session II: "Progress in Data Base Development"
Theordore L. Leininger, DuPont Company
Peter Winter, CAD Centre, Cambridge, England "Data Base Frontier in Process Design".
R. Peter Dube, Boeing Computer Services "Data Base Technology Applied to Engineering Data"
Raymond A. Lorie and Wilfred Plouffe, "Relational Data Bases for Engineering Data"

Session III: "Computational Algorithms"
Gary E. Blau, Dow Chemical
Gordon Bradley, Naval Post Graduate School "Mixed Integer Programming"
Warren D. Seider, Univ. of Pennsylvania "Physical Insights to Aid in Model and Algorithm Formulation"

Session IV: "Physical Properties for Design"
Joseph F. Boston, Aspen Technology
John P. O'Connell, Univ. of Florida "The Structure of Thermodynamic Models in Process Calculations"

Session V: "Nonsequential Modular Flowsheeting"
Rodolphe L (Rudy) Motard, Washington Univ.
John D. Perkins, Imperial College "Equation-Oriented Flowsheeting"
Lorenz T. Biegler, Carnegie-Mellon Univ. "Simultaneous Modular Simulation and Optimization"

Session VI: "Design and Scheduling of Batch Chemical Plants"
Richard S.H. Mah, Northwestern Univ.
G.V. (Rex) Reklaitis, Purdue Univ. "Intermediate Storage in Non-Continuous Processes"
Harold N. Gabow, Univ. of Colorado "On the Design and Analysis of Efficient Algorithms for Deterministic Scheduling"

Session VII: "Complex Single Unit Design"
Bruce A. Finlayson, Univ. of Washington.
Warren E. Stewart, Univ. of Wisconsin "Collocation Methods in Distillation"
H.H. (Hank) Klein, JAYCOR Scientific Research and Development "Modeling Fluidized-Bed Chemical Reactors"

Session VIII: Contributed Papers
Cameron M. Crowe, McMaster Univ.
Richard S.H. Mah, Northwestern Univ.
D.I. Suhami (Exxon) "Scheduling of Multipurpose batch plant with product precedence constraints".
R.A. Siqul and Mr. Gani, Universtidad Nacional, Del Sur Argentina, "The production of properties and its influence in the design and modelling of superfractionator.
Angelo Lucia, Clarkson College of Technology, "Reduced cost solutions to multistage, multicomponent problems by a hybrid fixed point algorithm.
Thomas Wayburn, J.D. Seader, Univ. of Utah, "Solution of Systems of complex interlinked distillation columns by differential homotopy methods.
Mark A. Stadtherr, Univ. Illinois, Urbana "Strategies of simultaneous modular flowsheeting and optimization.
Mordechai Shacham, Ben-Guriov Univ. of Negev "Recent developments in solution techniques for systems of nonlinear equations".

Session IX: "Operability in Design"
George Stephanopolous, National Technical Univ., Athens.
Ignacio Grossman, Carnegie-Mellon Univ., Manfred Morari, Univ. of Wisconsin, "A Dialogue of Resiliency, Flexibility, and Operability-Process Design Objectives for a Changing World"

MORE INFORMATION ABOUT FUTURE MEETINGS

CAPE '83 CONFERENCE

CAPE '83 is the first international conference on computer applications in industry. It will be held April 25-28 at the RAI Congress Centre, Amsterdam.

The conference is bringing together all aspects of the product process: product specification, design synthesis, verification, detailing, production, test preparation, manufacturing, assembly techniques, distribution, archiving and product documentation.

Papers in the following areas are scheduled:

1. State-of-the-Art
2. Socio-economic Aspects and Human Interfaces
3. Fundamentals
4. Information Processing Techniques
5. Industrial Techniques
6. Industrial Applications
7. Future Trends

Registration forms can be obtained from:

Organisatie Bureau Amsterdam BV
Europaplein, 1078 GZ Amsterdam
The Netherlands

PROCESS CONTROL

A four and one half day research conference on "Chemical Process Control" is planned for the summer of 1985. That conference will be the third of its type. The second one was held in January 1981 at Sea Island, GA. Its proceedings were published in 1981 as P-33. The first conference was held at Asilomar Conference Grounds, Pacific Grove, CA in January 1976. Its proceedings are Number 159 in the AIChE Symposium series.
Tom McAvoy (Maryland) and Manfred Morari (Wisconsin) will be the co-organizers for the planned conference.

TOPICS FOR 1984 CAST SESSIONS

New Computer Techniques for Solving Equations

Computer Modeling of Energy Processes

Advances in Process Synthesis

Advances in Personal Computing

Computers in Process Design and Analysis

Computer-Aided Design of Batch and Semi-continuous Processes

Process Data Reconciliation and Rectification

Application of Third Generation Microcomputers for Chemical Engineering Calculations

Microcomputers in Lab Data Acquisition and Control

Combinatorial Optimization

Product Scheduling

Networking- Hardware, Software

Computer Control Software

Topics in process control (2 sessions)

Modeling and identification (1 session)
Process fault detection and diagnosis (1 session)

Control problems in fossil fuel conversion processes (1 session)

Optimization of large operating industrial processes (1 session)

Integration of Process Control Into Process Design

Incorporation of Process Control Design into CAD Process Engineering Systems

NON-COMMERCIALISM POLICY

To promote technical excellence and to avoid commercialism or a sales approach in national and annual AIChE meetings, Executive Board of the Program Committee adopted the following policy:

"The aggressive promotional use of trade names or other forms of commercialism in titles, text or figures is not allowed. Authors may be shown as associated with companies and companies may be mentioned in acknowledgements. Presentations which are promotions of a commercial product or process shall not be made."

USERS GROUPS

ECES/FRACHEM

The fifth ECES/FRACHEM Users Conference was held in Parsippany, New Jersey, January 26-27, 1983. In addition to presentations from industrial users on their experiences, detailed reports of the enhancements made by OLI Systems were presented, including the status of the development of a flow sheet compatible version 3 were distributed. Chem Solve reported on the ECES Data Service and the plans for the 1983 data book and its initial data on binary systems (strong electrolyte-water or non-reacting gas in water). The guest lecture by James J. Fritz of Penn State University, was presented in Teleconference mode. He has been studying the chloride complexes of CACI in aquaous solution.

ASPEN

Approximately 50 engineers attended the Public ASPEN Users Group meeting on Monday, November 15 and 16 at the Los Angeles AIChE Annual Meeting. The Monday meeting was highlighted by election of officers, committee reports and talks on the "Status of the ASPEN Code" and "Experiences of a 100% User of the Public ASPEN Codes." The second day was highlighted by a presentation on "Methodology of "Bug-Finding". Two manuals were made available to users at cost. ARCO Chemical Company and J.S. Dweck, Consultant, Inc. are issuing an ASPEN Data Regression Users Manual. Another manual, An Introductory Manual, is available from ASPEN technology, Inc. Although written for ASPEN Plus, it is compatible with the public version with a few minor exceptions.

New Officers are:

Chairman: Henry M. Gahrhardt of Amoco Chemicals Corp.

Vice Chairman: Keven E. Wilson of Procter and Gamble Co.

Secretary: Stephen Solomon of Stauffer Chemical Company.

Arrangements are being made to hold the next general meeting of the ASPEN Users Group at the Houston National AIChE Meeting.

CURRENT CAST PUBLICATIONS

S-214. Selected Topics on Computer-Aided Process Design and Analysis. Papers selected from AIChE Meetings in New Orleans in November 1981 and Orlando in March 1982. Contents: Steady-State and Dynamic Simulation and Design of Chemical Processes. Equation-Based Process Flowsheeting System: An Equation-Oriented Approach to the Structuring and Solution of Chemical Process Design Problems. Simulating Methanol Plant. Flowsheet Simulation at ALCOA. Analysis of Thermodynamic Cycles. Comparisons of Distillation Networks-Resilient Heat Exchanger Networks. Adaptive Randomly Directed Search.
1982.144 pp. AIChE,$17.50;others$35.

M-13 Advanced Process Engineering. The Practice of Process Engineering, Data Base for Process Work, Process Component Models, Computer-Aided Process Design, Dependability Analysis, Process Synthesis, Energy Systems, Engineering Research, and Education for Process Engineering.
1980. 44pp. AIChE,$80.00;others,$20.

W-10 Industrial Process Control. The 21 papers in this volume discuss the current state-of-the-art of the technology and methodology for control of important processes and unit operations found in most petroleum and petrochemical plants.
1979.126pp. AIChE,$12.50;others,$25.

P-23 Proceedings of the 1979 Joint Automatic Control Conference. Broad coverage of process control including information on microprocessors, optimization, digital signal processing, linear multivariate and inferential control, simulation, biomedical applications, biofeedback, estimation, feedback and guidance control.
1979. 923 pp. $120.

P-7 Proceedings of the 1974 Joint Automatic Control Conference.
1974. 850 pp. AIChE, $60; others,$70.

ED-1. Fundamentals of Process Analysis and Simulation by K.B. Bischoff and D.M. Himmelblau.
1967. 32pp. AIChE, $7.50; others, $20.

S-55. Process Control and Applied Mathematics.
1965.167pp. AIChE,$10.00;others, $22.

SEVENTY-FIVE YEARS OF PROGRESS

1908 1983

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