INSTRUMENTATION AND AUTOMATION IN THE PAPER, RUBBER, PLASTICS AND POLYMERIZATION INDUSTRIES 1986

Edited by

A. KAYA and T. J. WILLIAMS

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Edited by

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FOREWORD

This is the 6th PRP Symposium and the first one held in America. The format of the Symposium was arranged so that the presentations were divided into two parts as in Pulp & Paper and Rubber & Polymers. Simultaneous sessions in these two areas covered the techniques and applications in depth while plenary sessions put a light into and set the pace for both the sessions to follow.

The main theme has been the improved productivity and product quality, which were reflected in papers in terms of better sensors and new sensing techniques; advanced control and optimization methods; and applications including dedicated controls as well as plant-wide optimization and scheduling.

Microprocessors have played a dominant role to meet the challenge set forth for practitioners to implement the control techniques developed.

Ten technical sessions in modeling and control of different processes in both industries have addressed the critical issues related to the theme of the symposium. The Round Table Discussion helped summarize what is accomplished and what are the future needs.

I wish to thank the Edison Polymer Innovation Corporation for their support. I would like to express our gratitude to Bailey Controls Company and especially to M.A. "Bud" Keyes (V.P. of Babcock & Wilcox) whose strong support and commitment made this conference possible and successful.

Furthermore, the credit goes to the International Program Committee chaired by T.J. Williams to generate high quality papers. Also, the college of Engineering at the University of Akron is acknowledged for hosting the event through its Industrial Control and Instrumentation Group.

Azmi Kaya

OPENING SESSION

WELCOME
A. Kaya (Gen. Chmn .)
The University of Akron
Akron, Ohio U.S.A

The story on IFAC and PRP-Automation Conferences will be told by my colleagues. The question is why the 6th PRP Conference is held in U.S.A. instead of its usual place of Belgium is an interesting one. It started out by my asking a "never-asked" question of why always in Belgium? Then, there it was PRP-6 in U.S.A. There are many places in U.S.A. The selection of Akron is based on many factors. Akron is the place where rubber industry started; the polymer industry is growing and the people in N.E. Ohio are working hard for revitalizing the area into a Polymer Valley. Also, I personally happen to be here, in a right place at the right time. I welcome all of you here and hope for a rewarding conference.

WELCOME ADDRESS ON BEHALF OF
IFAC
Achille Van Cauwenberghe
University of Ghent, Belgium

I like to convey the best wishes for a successful conference to all of you on behalf of IFAC and its President Professor Manfred THOMA. For those who are not quite familiar with IFAC, let me explain how it originated and how it operates.

On September 12, 1957 delegates from 18 countries founded IFAC, the International Federation of Automatic Control. Harold Chestnut (U.S.A.) was elected to be the first President.

Now nearly 30 years later 43 national member organizations constitute the membership. About 10.000 people participate each year in the numerous symposia and conferences sponsored by one or more of the 14 technical committees of IFAC. These cover a wide range of interests, ranging from mathematics and theory of control to process control, manufacturing technology, transportation, economic and management systems; from computers and space applications to social effects of automation.

The purpose of IFAC is to promote the science and technology of automatic control in the broadest sense in all systems, including engineering, physical, biological, social and economic systems. It is also concerned with the impact of automatic control on society. IFAC has neither political nor economic aims. It pursues its purpose by organizing technical meetings and conferences and by its publications (mainly the Journal Automatica and the IFAC Proceedings Series; a multilingual dictionary of control terms is regularly updated as well). Every 3 years it organizes a World Congress attended by some 2.000 people, e.g. Kyoto 1981, Budapest 1984 and next year Munich 1987. A well-tuned predictor can already distinguish at the horizon Tallin 1990, Australia 1993 and the U.S.A. that is willing to organize the 1996 World Congress.

The PRP- Automation conferences started in Belgium nearly 20 years ago: to be specific in Antwerp 1966 and Brussels 1971. Their success has been growing and the PRP-conference is now part of a well-established series: Brussels 1976
Ghent 1980
Antwerp 1983

For the first time the conference is now organized at the other side of the Atlantic. We trust that the series will continue to be useful to engineers and scientists in pulp and paper, rubber, plastics and polymerization industries. The present conference will certainly reflect the impact of high-tech and recent control theory advances in the PRP-process industry. We sincerely hope that it will be the successful platform of exchange of experience and recent progress in this field.

The conference is sponsored by the applications Committee of IFAC and its chairman Prof. KEVICZKY from Budapest asked me to convey his best wishes to all conference attendees.

The American Automatic Control Council (AACC) represented here today by W. Miller and the organizers of the conference, particularly Prof. T.J. WILLIAMS, the IPC chairman and Prof. A. KAYA, the chairman of the Local Organizing Committee should be congratulated with the fine program they are offering us. they succeeded in preparing the right feed stock of papers to be presented, in order to get an excellent product out of this conference. Consistency and basis weight are guaranteed to satisfy both theoreticians and practitioners, academics and industrialists alike.

The location of the conference is quite unique. Not only do we meet in Akron the Rubber capital of the world but the conference is also convened in a renovated and reconverted mill. The organizers that make us "sleep in a silo, dine in a depot and meet in a mill" have certainly demonstrated that science should benefit from industrial practice. ..e conference will prove to us that the reverse also holds. May this conference once again be an example how to apply theory and technology to the benefit of mankind.

WELCOME ADDRESS ON BEHALF OF
IMEKO
G. Toumanoff (President, IMEKO)
U.S.A.

It is very gratifying to take part in the first PRP Conference in the United States and only the second time IMEKO has been a sponsor of an event on this side of the Atlantic. The first IMEKO Congress took place in 1958, in Budapest. Only a handful of organizations took part, but it was recognized that a gap in the general structure of international technical meetings was being filled. Western participants were invited to the second Congress in 1961 and from then on IMEKO became a formally constituted international "umbrella" Confederation of national technical societies representing the measurement sciences and instrumentation technologies of their respective countries.

IMEKO is now comprised of thirty Member Organizations, each a professional, non-governmental society representing its national activities in the fields of metrology, measurement science, instrumentation technology and applications. In this respect we are very similar to our sister federations, IFAC, IFORS, IFIPS and IMACS banded together in FIACC to coordinate our interests and cooperate in our meetings. PRP-6, I might note, is co-sponsored by three of the five.

Measurement is pervasive throughout all industry and applications of technology. In this respect our actions must be carefully executed lest we overlap unproductively in the activities of other technical bodies. thus, we are particularly pleased to be co-sponsors of conferences such as this one and to have other societies join in our efforts. The most important of these is our tri-ennial Congress. The next one, being also for the first time on this side of the Atlantic, will take place in Houston, October 16-21, 1988. You are all most welcome to IMEKO XI.

In common with our peers we are organized in matrix fashion by national MOs and specialized Technical Committees. Congresses, symposia, conferences and seminars are hosted by an MO and technical expertise is supplied by the TCs. Except for a Congress, the initiative for a meeting comes from a TC. A most important concern of IMEKO is to transmit our knowledge to the technicians in developing countries learning to utilize modern industrial methods. Among our 15 TCs one, TC-11, is devoted to furthering such knowledge transfer and regularly organizes tutorial meetings to provide training in measurement skills.

IMEKO's outlook is undergoing a major "sea change". Although our Congresses have been held from London to Moscow and our membership ranges from Australia to Yugoslavia we have operated as an essentially European activity. With our 1988 Congress in the U.S.A. and committed to China for 1991 we are going Global. See you in Houston!

OPENING SESSION REMARKS ON TECHNICAL PROGRAM

Theodore J. Williams (Chmn., IPC)
Purdue University
West Lafayette, Indiana, U.S.A.

Good Morning Lady and Gentlemen:

In the name of the International Program Committee it is my pleasure to join my associates here in welcoming you to PRP-6 and our Technical Program.

We hope very much that each of you will find the program of our Conference technically rewarding and that you will enjoy the papers and get ideas from them which you will find useful in your own work back home.

Our program is almost equally divided between topics related to the rubber and plastics field on the one hand and the pulp and paper field on the other - five sessions each and 18 papers versus 24 for a total of 42. I understand earlier programs were more heavily weighted toward the paper field.

We are happy to present you with a book of the Preprints of the Conference. Like most of our compatriots we have had our minor problems with late authors. Three of the papers, including one of the plenary papers, are being passed out separately. Unfortunately we lack manuscripts at this time on three of the papers (one in Session 1 and two in Session 10).

You have undoubtedly already noticed that the regular technical papers are being presented in two parallel sessions - one in rubber and plastics and the other in the pulp and paper area. We hope this arrangement will give the best service to you, the attendees. We do invite each of you, however, to stop in at one or more of the "other sessions" to hear the latest in technology there.

We are especially grateful to our plenary session speakers for their great service to all of us in preparing and presenting their surveys to us.

Professor Van Cauwenberghe, as you know, is the original organizer of this series of Conferences. We hope he is pleased with this first presentation of his Conference outside of Europe. We will look forward to hearing his discussion of the place of Adaptive and Predictive Control in the paper Industry this afternoon.

Concepts of Adaptive Control as applied to the plastics industry will be presented for us by Ing. Dormeier of the University of Paderborn tomorrow morning.

Professors Kamal and Patterson of McGill University will review for us the measurement and modelling problems of plastics processing of non-sheet products on Tuesday afternoon.

Dr. Cy Rutledge of the Mead Corporation in the fourth plenary will review for us the user's needs for sensors in their production of sheet products and the developments we can expect in the near future in that area.

Finally as Chairman, may I take this moment to thank each and every one of the members of the International Program Committee for their hard work in making this program possible. May I also take this opportunity to announce to them that we will have a final meeting of the IPC this evening after the Cocktail Party here in the hotel in Ballroom A at 8:00 p.m.

Again, may I welcome you all to the Technical Sessions of PRP-6. I hope that you enjoy the Conference very much

Thank you.

KEYNOTE ADDRESS

Doug Cannon

President, Bailey Controls Co., Wickliffe, Ohio, USA

Instrumentation and controls plays a critical role in revitalizing our industries - whether that industry be located in the United States, China, Canada, Bulgaria, Sweden or wherever. Yet, we find in even the most advanced countries a majority of industrial firms have not realized the promise of this technology. Why is this so? And who's responsible? Is it solely the reluctance of the industrial user? Should we point the finger at the limited capabilities of the instrumentation and control suppliers, or is it the lack of vision provided by the academic community? The rapid development of microprocessors has blurred the traditional distinctions between mainframes, mini-computers and micro-computers.

Twenty years ago, the high cost of rapid access to limited memory storage created a generation of software wizards with an uncanny knack of putting 10 pounds of software programs into a 5 pound memory. Today, for all practical purposes, memory can be considered to be free.

Hardly a day passes that we do not see some new innovation or development which promises improved efficiencies and !ower costs. This is nowhere more apparent than in the semiconductor chip industry.

One rule of thumb is to merely look at the amount of hardware to perform a comparable function. this is by far the most conservative approach. It would indicate a five-fold increase in control capability. Perhaps that's fair. Not all aspects of control, such as measurements and actuators, have improved to the same extent as others.

This five to one improvement should be even more effective when you consider the increased share of capital investment for instrumentation and control.

We are all in the instrumentation and control business. We should not be classified as suppliers, users or teachers. The institutions and the organization charts may give us labels which tend to separate us. But our instrumentation and control commonality is much stronger. We participate in a business which has the broadest range of challenges imaginable. New application ideas, new product designs, successful implementation of major automation projects can be attributed to each of our institutions.

Beginning with the introduction of the computer and electronic systems to process control, a division of labor emerged in the industry. Specialization became even more narrow as applications became more complex. Today's technology can ease the implementation of control strategy and data management so that the process control engineer can more effectively merge the process and control technologies. I repeat that the technology can help. But it doesn't guarantee it.

We too must be more responsive to the new technology which can simplify our own process, and make the process control engineer more effective.

The importance of the complete process control engineer is even greater as the demand for plantwide automation increases.

Today there is much broader appreciation for what our product is. Very few cling to the old, narrow perception of our product as just an assembly of electronic components or a series of programs with specific features. Most would accept that we produce control applications. Total process includes the availability of raw material, major processing equipment, support systems, material handling, performance data and the operator. With this perspective, our product moves closer to the process objectives.

The power of the microprocessor and low cost memory circuits are readily available in effective packages for broad ranges and levels of process automation. A common technology may now be used where up to four separate technologies were previously required.

New methods for distributed processing and intelligence make the task much simpler to implement and coordinate as the applications expand to the total plant.

Interactive graphic display technology can provide virtually unlimited communication capability between the operator and the process.

The greatest factor in realizing the potential of this plantwide concept will be the continuing resurrection of the total process control engineer.

I don't mean to imply that the process control engineer is the only important individual in the industry or even the most important. What is most important is the concept of the role of the process control engineer.

That concept will drive the universities to produce engineers who understand both the process as well as the control technologies.

In the user organizations, it will help communicate the increasing benefits of instrumentation and automation to top decision makers.

And, not least of all, it will focus suppliers on the need to develop the simple, cost effective, but powerful tools which help the process control engineer direct those new developments at the improved throughput and quality of the users product.

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APPLICATIONS OF ADAPTIVE AND PREDICTIVE CONTROL IN THE PULP AND PAPER INDUSTRY

A. R. van Cauwenberghe

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Abstract. First a short overview is given of different methods of adaptive and predictive control, which are promising for application in industry. Not only the methods but also the already commercially available control instrumentation is discussed. The main body of this survey consists of a review of applications of adaptive/predictive control in the pulp and paper industry.

Keywords. Adaptive control, predictive control, Recursive parameter estimation, Pulp and paper industry, Self-tuning control, PID autotuners.

INTRODUCTION

Adaptive control is becoming of age. The first theoretical developments date from the late sixties. They have been refined and improved continuously. Much work has been done on the stability and convergence of estimation schemes and on the rebustness of the different designs. Recent surveys deal with these in detail : Åström (1983), Åström & Wittenmark (1985), Isermann & Lachmann (1985), Isermann (1985), Unbehauen (1985).

However, introduction of adaptive controls in industry has been slow. Many difficulties had to be solved in order to obtain a sufficiently simple and safe operation. Exhaustive accounts on more or less successful applications in the process industries have become available recently : Seborg, Edgar, Shah (1986), Dumont (1986 a,b).

It is fair to say that the whole area has reached some maturity. Theory and algorithms have been improved considerably. The emergence of several industrial products on the adaptive control market is a clear sign of growing confidence. Leeds and Northrup announced their Electromax V, a single-loop controller with self-tuning option already in 1981. One year later the Swedish ASEA introduced their Novatune, a small DDC system with several adaptive modules, among others a minimum-variance self-tuning controller. Three adaptive controllers were announced in 1984. The British company Turnbull Controls introduced their TCS 6355 auto-tuning controller, which is a single-loop regulator with adaptive and auto-tuning facilities. The Swedish NAF Controls have an Autotuner which is based on the Ziegler-Nichols oscillation method to tune PID regulators automatically. Foxboro announced their adaptive single-loop regulator Exact. Meanwhile, several other adaptive controllers have been announced or are about to appear e.g. Brown Boveri, Toshiba, Doric Scientific and others. Today, several thousand loops are already under adaptive control. The practical experience from their operation is accumulating and will certainly lead to further improvements.

These products are based on different concepts and regulator/controller structures. Most are based on the PID-algorithm (so-called "autotuners"), others on more advanced and more general algorithms as minimum-variance control. Some use the traditional approach to adaptive control based on recursive parameter estimation (usually a least-squares method), but others are using less conventional methods for estimation and control design. For example, the Foxboro Exact controller uses an heuristic design method which mimics the tuning procedure of an operator. The NAF Autotuner uses a novel method to determine the process dynamics from relay oscillations.

Most adaptive methods currently used are local gradient algorithms. Given good initial values they will drive the system to a very good performance. The effort required to obtain the initial values or the prior knowledge may be substantial. There is also a growing awareness of the need for safeguards to ensure that the adaptive regulators perform well under all possible operating conditions.

Prior to reviewing the applications in the pulp and paper industry, a short overview will be given of some of the most promising adaptive control schemes. For autotuning of PID-controllers we refer to Åström (1986).

ADAPTIVE and PREDICTIVE CONTROL

Over the years, academics have coined new terms to describe different approaches to adaptive control. Unfortunately, manufacturers have not always followed this terminology for their new products. This is sometimes misleading if one wants to know the underlying theoretical method and its algorithm used for a particular commercial controller.

An adaptive controller is a loop controller with adjustable controller parameters together with some built-in intelligence in the form of mathematical algorithms. These are used to adjust the parameters in order to improve the control performance. The difference between the various implementations lies in the way in which the control performance is evaluated and how the control parameters are calculated.

The oldest form of adaptation used in automatic control is called "gain scheduling" or "adaptive gain" control. In this scheme the gain and in some cases also the integral and derivative terms can be adjusted automatically on-line. These adjustments are however predefined by the user as simple functions of either the measured variable, the controller output or the error signal. Once defined, this preprogrammed schedule usually remains fixed, the object being to adjust the loop coefficients to compensate for known nonlinearities in the process e.g. pH characteristics or in the actuators e.g. valve characteristics. Clearly, the full benefits of gain scheduling can only be achieved if the changes in the process characteristics are well understood and these relationships do not change with time.

A block-diagram of a more general adaptive regulator is shown in Fig. 1. It contains an ordinary linear feedback regulator in the inner loop. The control parameters of the regulator are continuously adjusted by the outer loop, which performs recursive parameter estimation and control design calculations.

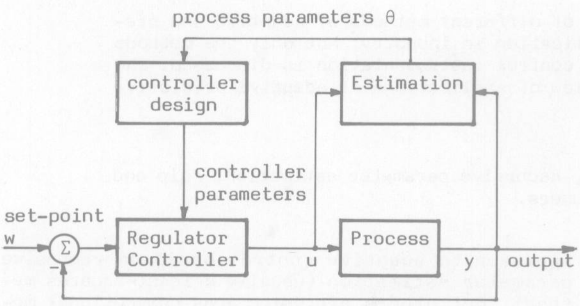

Fig. 1 : Conventional adaptive regulator/controller.

The block labeled "controller design" represents an on-line solution to a controller design problem for a system with known parameters. The scheme represented is very flexible : both model-reference adaptive control systems (MRAC) and self-tuning control (STC) can be represented by it. Many different controller design and parameter estimation schemes can be used. Minimum variance (MV) of the output is a common design method, but also pole-placement and linear quadratic gaussian optimal control are often used. If the MV is generalized to include the control effort (Clarke-Gawthrop method) also nonminimum phase processes may be dealt with. Different parameter estimation schemes have been used : generalized least squares being most popular, besides stochastic approximation, instrumental variables, maximum likelihood or extended Kalman filtering. If the estimated parameters for the time-varying process converge to the real values for the process with known parameters the controllers is said to be self-tuning. This characteristic is more often realized than can be proven theoretically. If disturbances are included in the process model the controller will contain a feedforward term.

The STC shown is called an indirect selftuner i.e. based on the explicit estimation of the process parameters. It is often possible to reparameterize the process so that it can be expressed in terms of the control parameters. In this case the estimation algorithm gives direct estimates of the control parameters : the block "controller design" disappears from Fig. 1. This direct scheme (implicit self-tuning) is used in the ASEA Novatune.

An advantage of the indirect adaptive scheme is that many different design methods can be used. Intermediate results are easily accessible and the scheme can be extended to multivariable and nonlinear processes. The key issue is however to show that the estimates converge. Generally this will require that the model structure used is appropriate and that the input signal is persistently exciting. The direct adaptive control schemes are simpler. They also work well even if the model structure used is not correct. Of the four explicit (indirect) self-tuning controllers which are currently available, two use simple 1st-order lag plus deadtime models, one uses a 2nd-order process model and one a 2nd-order model with dead time. Clearly, if the model does not provide a sufficient number of terms to describe the dynamics, one can hardly expect to get better results than with an adaptive PID-controller.

Recently there has been considerable interest in adaptive controllers based on predictive control. These are based on estimation of the following ARMA-model :

$$A(z^{-1})y(t) = B(z^{-1})u(t-d)+C(z^{-1})e(t)$$

with t = discrete time index
d = time-delay index ($d>0$),
delay time $\tau_d=(d-1)T_s$ (T_s : sampling period)
y = process output
u = process input or control variable
e = uncorrelated stochastic noise

$A(z^{-1}), B(z^{-1}), C(z^{-1})$: polynomials in the backwards shift operator z^{-1}

The specifications are often expressed in terms of the desired step response of the closed-loop system, which is easy to describe to the operator. There are many different algorithms of this type e.g. :

- the extended horizon minimum variance control (Ydstie, Kershenbaum and Sargent, 1985) minimizing the quadratic deviation of the predicted output from the desired value, at one particular point k-steps ahead in the future;
- the extended prediction self-adaptive control (Van Cauwenberghe & De Keyser 1985; De Keyser & Van Cauwenberghe 1982, 1985; Martin-Sanchez, Shah & Fisher 1984) minimizing this quadratic deviation over a range of future moments.

With proper choice of the horizon, these methods can handle nonminimum-phase processes with unknown deadtime. The length of the prediction horizon can be adjusted to find the best compromise between output and input variances. These schemes are very robust and hence of major practical importance. Recent generalizations include on-line tuning of the time horizon to satisfy a stability condition of the closed loop (Ydstie 1986).

There are also variations based on linear quadratic optimization criteria (Lemos and Mosca 1985). All these algorithms are related to dynamic matrix control DMC (Cutler and Ramaker 1980), model algorithmic control (Richalet 1978) and internal model control (Richalet and Papon 1985).

In contrast to the self-tuner the (response analyzing) autotuner has been developed almost independently of the main academic work. Whereas the STC uses a formal process model and design procedures which are typically used at the control design and planning stage, the autotuner mimics the practical procedures which are executed by the engineer (expert operator) during commissioning. Autotuners operate by monitoring and analyzing the process error signal either in response to a startup transient or to naturally occurring or injected setpoint changes or load disturbances. Once analyzed in terms of traditional performance specifications as risetime, overshoot, gain margin etc. heuristic rules are used to modify the control parameters using rules-of-thumb or Ziegler-Nichols procedures.