

# Preface

## History and Meaning of the Book

This book is a history and learning explanation of the results achieved over more than four decades of research, development, and realization of process control systems by the authors and their collaborators. It is almost chronological and includes the contents of three previous books that summarized, at different times and in a similar way, the advances made by this effort.

In the early 1970s, several publications stated that there existed a gap between the theory of process control and its industrial application. In a well-known paper entitled “Critique of Chemical Process Control Theory,” published in 1973 by the *American Institute of Chemical Engineers Journal* (Vol. 19, No. 2), Professor A.S. Foss, from the University of California at Berkeley, examined the process control problems of the chemical industry and the practical inadequacies of optimal and adaptive methodologies available at that time. These methodologies had tried to overcome the well-known limitations of PID negative feedback controllers. In a clear way, he also suggested the required characteristics of a solution able to meet the needs of industrial control. It had to exploit interactions inherent in multivariable physical processes and be adaptive, but stable, even in the presence of unmodelled dynamics, unknown perturbations and imprecise knowledge of parameters and measurements. He placed special emphasis in that the control objective or performance indices, the meaning of which were not clear in the available theories, be transformed into criteria that had “fundamental and physical meaning” within the ultimate framework of the theory. He concluded the paper stating that “the gap was indeed present, but contrary to the views of many, it was the theoretician who had to close it.”

In October 2012, a Special Issue entitled “Industrial Optimized Adaptive Control,” published by the *International Journal of Adaptive Control and Signal Processing (IJACSP)* (Vol. 26, No. 10) defined the concept of “Optimized Process Control Performance” as follows:

“This concept implies first that the control system under consideration must be able to achieve the dynamic stabilization of the process, i.e. this means be able to maintain, within the range of attainable operating points, the process variables under precise control around their setpoints with adequately bounded control signals, in spite of changes in process dynamics, context of operation and noise and perturbations acting on the process.

Secondly, the control system must be able to achieve transitions between the attainable operating points in which the process variables under control are driven through desired trajectories with adequately bounded control signals.

Thirdly, the control system has to be able, in real time, to look when necessary for the process operating point that satisfies a criterion for the optimization of the process performance and drive the process variables towards this optimal operating point.”

Obviously, the previous concepts of dynamic stabilization of the process and optimized process control performance are not well-defined mathematical concepts. Due to the usual complexity of the industrial operating context, these concepts have been derived from an industrial application perspective, where the best possible control performance can only be defined in a qualitative manner and be confirmed by the common sense criteria of the human process operator.

The design of industrial control systems, and particularly those aimed at optimizing process control performance, is necessarily based on available knowledge of the process dynamics and the use of a control methodology. The simple use of controllers based on a control methodology is not often able to achieve what we have defined as optimized process control performance. However, from the available process knowledge we can derive process control strategies in which the controllers can be integrated in order to achieve the best control of the process. When the combination of process control strategy and control methodology enables optimized process control performance, we will talk about optimized process control strategy and optimized process control system.

The same special issue also defined the class of “Optimized Adaptive Control Methods”, characterized by: (i) a predictive model of the plant whose parameters are adjusted in real time by an adaptive mechanism in such a way that the prediction error converges toward zero, and (ii) this predictive model is used at every control instant to derive a desired future process output trajectory by minimizing an index that is chosen according to a performance criterion.

For these control methods the adjective “optimized” corresponds, in this case, to a rigorous mathematical formulation. Two different approaches in the development of optimized adaptive control can be identified. The first one is based on a stability perspective and the second one is based on an optimization perspective. These two kinds of optimized adaptive control were developed in an independent manner, but a joint survey of both of them and their connections was also presented in the Special Issue.

This book makes a clear distinction between the concepts of controller and system. While a controller results from the application of a control methodology to a process in order to guide under certain criteria the evolution of a set of its

variables, a system results from the application to a process of a control strategy in which one or several controllers are integrated in order to improve the overall performance of the process. Thus, controller is a local concept that operates in the context of a so-called control loop that determines the evolution of a set of process variables, while system is a global concept that may include one or several control loops acting on the context of a process according to a control strategy.

This book focuses on the developments of optimized adaptive control made from the stability perspective, which are a natural extension of the original work on adaptive predictive control. This explains why the terms “Optimized Adaptive Control” and “Adaptive Predictive Control” are often used with the same generic meaning in this book. It also focuses on the design and implementation of optimized adaptive control systems that use Adaptive Predictive Expert (ADEX) controllers within the optimized control strategy. ADEX control is the latest methodological development of optimized adaptive control from the stability perspective.

In addition, the IJACSP special issue stated and demonstrated that the use of optimized adaptive controllers, integrated in the appropriate control strategy, can solve the industrial process dynamic stabilization problem and approach optimized process control performance in industry. When an optimized control system integrates optimized adaptive controllers, we will talk about optimized adaptive control system.

This book presents the principles of predictive control and adaptive predictive (AP) control, in which the body of optimized adaptive control theory is based, as they were originally formulated and subsequently presented in a book entitled “Modern Control Theory: Adaptive Predictive Method. Theory and Applications (In Spanish)”, published by the Juan March Foundation of Spain in 1977. Next, it explains how the basic concept of predictive control was broadened by introducing in a patent application, filed in 1980, a performance criterion in an extended prediction horizon, and how this criterion could incorporate a fundamental and physical meaning for process performance optimization.

On the adaptive side of the predictive model, stability was the first requirement, and this book presents the methodological developments that guaranteed the dynamic stabilization of the process, even in the presence of unmodelled dynamics, unknown perturbations and imprecise knowledge of parameters and measurements. It also presents the stability theory that supports the practical application of these developments, gathering together the results of the original sources published in the literature, from 1976 to 1996.

The significant advantage of stable optimized adaptive control systems, which can be derived from the first four parts of this book, is the satisfactory convergence toward optimized process control performance when the control system faces uncertainties characteristic of the dynamic behavior of industrial processes. This book presents the first benchmark applications of adaptive predictive control or stable optimized adaptive control, illustrating their implementation, and showing their ability to deal with process dynamics and perturbation uncertainties. As a matter of fact, a first generation of stable optimized adaptive control systems was

successfully applied to a wide variety of processes in various industrial areas, as described and illustrated in the book entitled “Adaptive Predictive Control: From the Concepts to Plant Optimization,” published by Prentice Hall in 1996.

However, the question was posed: Why let the controller deal with uncertainties that we already know, at least in part, prior to its application? This led to the development of a new generation of optimized adaptive control named “ADaptive Predictive EXpert Control,” or “ADEX,” which provided an additional facility for capturing a priori plant knowledge.

Essentially, ADEX combines optimized adaptive control with expert control by defining an integrated control structure with different operating domains, where one of these two control methodologies is applied in each domain. It is the evolution of process variables and/or the occurrence of any other preset event, which determines the operating domain and accordingly whether optimized adaptive or expert control is applied to the process. Thus, the controller designer can configure the selected type of control taking into account prior knowledge of the process dynamics and surrounding uncertainties in the corresponding control domain. This configuration permits the ADEX controller to take advantage of available process knowledge during its operation, as this is useful for a faster convergence towards stability or optimized process control performance.

A book entitled “Adaptive Predictive Expert Control: Methodology, Design and Application (In Spanish),” published in 2005 by the Universidad Nacional de Educación a Distancia (UNED) of Spain, presented ADEX methodology and a software platform, named ADEX COP (Control and Optimization Platform), which enabled the integration of ADEX controllers into control systems, PLC and DCS, currently being used in industry. Also, it illustrated ADEX COP application to an example of a complex, time-varying, and multivariable process, subjected to measurable and non-measurable perturbations.

The ultimate objective of this book is to provide the reader with a complete set of proven theoretical concepts and practical tools for the development of industrial optimized adaptive control systems. In order to be as self-sufficient as possible, this book revisits the contents of the three previously mentioned books, and describes the implementation of two new different ADEX platforms, currently being used in industry, to two illustrative plants in the energy and petrochemical areas. One of these two platforms allows the design and application of optimized adaptive control systems in parallel with the operation of the existing plant control system. The other platform allows developing optimized adaptive control systems embedded in the local control system of the plant.

The particular learning approach and the detailed contents of this book, divided in Parts and Chapters, exercises, and experimental practical applications in simulation, are described in a separate section that follows this Preface.

## Who This Book Is Intended for

This book is directed toward degree and doctoral students in engineering and applied sciences, professional engineers, and researchers who have an interest in the area of automatic control, and particularly, in advanced control methodologies. With the purpose of making its contents interesting and comprehensible for a broader spectrum of potential readers, from readers more motivated by the theory to those more oriented toward practical applications, we have tried to avoid the complexity of books dedicated strictly to control theory, while maintaining the scientific rigor.

## Acknowledgments

This book summarizes the results of research and development work completed during more than four decades by the authors and their collaborators. These collaborators are the first to deserve our recognition for their help and contribution to this book. So, we wish to express our gratitude to professors Sirish L. Shah and Grant Fischer of the Chemical Engineering Department at the University of Alberta (Canada), Professor William Cluett of the University of Toronto (Canada), Professor Guy Dumont of the University of British Columbia and the Pulp and Paper Research Institute of Canada (PAPRICAN), Professors Tsu T. Soong and Andrei Reinhorn of the National Center for Earthquake Engineering Research of the State University of New York, Buffalo (USA), engineers José Calvo and Javier Malia of Canal de Isabel II, Madrid (Spain), Professor Antonio Favela, Dr. Angelo Raimondi, and engineer Raúl Estrada from the Instituto Tecnológico y de Estudios Superiores de Monterrey, Nuevo León (Mexico), professors Antonio Nevado, and Ricardo Requena from the Universidad Nacional de Educación a Distancia (UNED), Madrid (Spain), engineer Dr. Andrew Clegg from Industrial Systems and Control Ltd., Glasgow (Scotland), engineer Andrew Geddes from Scottish Power PLC, Glasgow (Scotland), and engineer Edgar Gracia of the Refinería Ing. Hector R. Lara Sosa, Pemex Refinación, Cadereyta, Nuevo León (Mexico).

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Our gratitude must as well be for the founders of the company Adaptive Predictive Expert Systems ADEX, S.L., created to develop ADEX technology and promote its first applications, and particularly to Antonio Gómez Iniesta and José

Javier Glaría Santamaría, whose creativity and dedication are responsible for the development of the first version of ADEX COP.

The entrepreneurial effort required to introduce ADEX technology to the process control market has been carried out so far by the company Adaptive Predictive Expert Control ADEX, S.L. We want to sincerely acknowledge this titanic effort, express our gratitude to the shareholders that made it possible, the company's manager Ken Slaven for his continued efforts and faith, and all the ADEXs staff for their excellent work, team spirit, and loyalty beyond the call of duty.

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