

Preface

In spite of limited knowledge about the process dynamics and under varying and unmeasured disturbance inputs affecting the process operational performance, design of a control system capable of maintaining an optimized operation of a complex dynamic process has attracted considerable attention of the industry and research community over last couple of decades. Although excellent progress has been made the problem is still challenging and of increasing importance. Design of a controller as a single entity with a homogeneous centralized decision mechanism is possible only in situations in which the process dynamics, uncertainty and the control objectives, are relatively simple, e.g., in the case of a stabilization of angular velocity of a d.c. motor. In many cases of complex multivariable processes, with seriously uncertain and nonlinear dynamics and under varying in time disturbance inputs, it is too difficult or simply impossible. Moreover, a general objective of the industrial complex process control in a market economy is to maximize economical efficiency over a long time horizon while maintaining its sustainable operation — and it is usually not easy and straightforward to translate these goals into trajectories or even steady-state values of the process controlled inputs. A well-established way to cope with a design of a controller in such complex situations is to apply a *hierarchical control structure*. The hierarchical structuring of the control system allows efficient handling of the process dynamics complexity and the uncertainty. Such an approach to the control system design is well-established in industrial practice and discussed in many papers and monographs. The main idea is to decompose the original control task into a sequence of different, simpler and hierarchically structured sub-tasks, handled by dedicated control lay-

ers. The reason is to make the control system design easier by creating technically well-defined and simpler subtasks requiring different theoretical and technical tools, as well as to improve the control performance and reliability.

In Chapter 1 and Chapter 2, the book comprehensively covers a multilayer control architecture for systems with a steady-state but varying in time optimal operation mode. The optimizing control algorithms are presented in Chapter 3 and Chapter 4. The modified model-based optimization and the model parameter estimation is integrated in the algorithms in such a manner that a true process optimum is reached after a number of control applications to the process have been made. The corresponding output responses are measured after the transients have died and the process has reached its new steady-state. The measurements are utilized in order to suitably modify the model based optimization problem and to update the model parameters. The resulting control technology is called *Integrated System Optimization and Parameter Estimation (ISOPE)*. It is extremely important that uncomplicated models of the process are needed but simple point-parametric models are sufficient. The resulting optimizing control algorithms are of the *iterative* type. The controlled process-based iterations are needed in order to cope with the uncertainty. A case when the constraints on the process output are active is separately considered in Chapter 5. The control structure is further developed as well as the optimizing control algorithms in order to efficiently handle the output constraints.

The algorithms are tested by simulation and applications to several case study examples are also presented. These are: ethylene distillation column, vaporizer pilot scale plant and styrene distillation line consisting of three columns.

The multilayer control structure remains the same for dynamic processes operating in a batch mode. However, the algorithms then become more complex, they are covered in detail in Chapter 6. An industrial furnace case study illustrates an overall process of control design and the application results.

Control structures and iterative optimizing control algorithms for complex controlled processes with a spatial structure are considered in Chapter 7. The *spatial decomposition* is applied, in addition to the *functional decomposition*, in order to support the latter in coping with the complexity. It is based on a division of the control task (or a functionally partial task — within one layer of the described multilayer structure) into local subtasks of

the same functional kind but related to individual spatially isolated parts of the entire complex control process — subtasks of smaller dimensionality, smaller amount of processed information. This procedure leads to so-called *multilevel structures* or *multilayer-multilevel structures*.

The most demanding is the dynamic continuous optimizing control, applicable to cases of systems operating in truly dynamic modes that cannot be split into the consecutive batches. A case study of an Integrated Wastewater System is given in Chapter 1 in order to illustrate the multilayer control concept applied to synthesize the dynamic optimizing control. In this case study most recent results on application of optimizing control to Integrated Wastewater Systems are presented, with temporal decomposition and repetitive Robust Model Predictive Control (RMPC) as key control technologies used, within the multilayer structure. The *temporal decomposition* is applied when, as in this case study, the task of control generation is formulated as a dynamic optimization problem and the controlled dynamic system (and/or disturbances) is multi-scale, i.e., there is significant difference between the rate of change of fast and slow state variables (and/or disturbances) of the system.

Strengthening the RMPC information feedback mechanism by combining it with the ISOPE feedback mechanism within the hierarchical structure that is presented in the book is seen as a difficult but very promising future research direction for further development of optimizing control systems.

The book presents basic structures, concepts and algorithms in the area of multilayer optimizing control of industrial systems, as well as the results of research that was carried out over the last two decades. It is addressed to several categories of readers, first of all to the research community and postgraduate students, but also to practitioners. In order to make the book more useful, longer or more difficult proofs of theorems were moved to the Appendices.

Acknowledgements

We are grateful to many people who have made contributions in various ways to this book. Our Ph.D. and D.Sc. degree research has been carried out in a group led by Professor W. Findeisen and located in the Institute of Control and Computation Engineering (formerly the Institute of Automatic Control), Warsaw University of Technology, where the second author is still employed. We are very grateful to Professor Findeisen and colleagues from the group, especially to Professor K. Malinowski and Dr. A. Woźniak, and from the Institute for the fruitful scientific atmosphere supporting the

research.

The first author spent a year in 1983 – 1984 in the Control Engineering Center at City University, London led by Professor P. D. Roberts, as Senior Visiting Research Fellow of SRC, UK. The second author visited Professor Robert's group at City University during 1986 and he has also been supported by SRC, UK. Our interests in ISOPE technology, a backbone control technology considered in this book, have been developed during those visits. Also, the vaporizer and furnace applications have been performed in the Control Engineering Center research laboratory. We have benefited immensely from these visits and we are very grateful to Professor Roberts.

We wish to thank our numerous Ph.D. students who have enthusiastically carried out their research and have successfully completed it achieving excellent results.

Special thanks go to Mrs. Mariola Lubińska and Mr. Tomasz Rutkowski from the Intelligent Decision Support and Control Group at Gdansk University of Technology, for help in preparing many figures for Chapter 1, Chapter 6 and Chapter 7. Discussions with all members of the Group were very useful in preparing the presentation of application of the hierarchical dynamic optimizing control to Integrated Wastewater System at Kartuzy, northern Poland.

Finally, we would like to thank our wives for their love, support and encouragement. Without their help and sacrifices, we could not have completed this book.

Mietek A. Brdys	Piotr Tatjewski
<i>Birmingham, Gdańsk</i>	<i>Warszawa</i>