

Preface

Adaptive Control provides techniques for automatic adjustment in real time of controller parameters in order to achieve or to maintain a desired level for the performance of control systems when the dynamic parameters of the process are unknown and/or vary in time. These techniques have as a main characteristic the ability to extract significant information from real data in order to tune the controller and they feature a mechanism for adjusting parameters (of a plant model or of a controller).

While the history of Adaptive Control is long, significant progress in understanding and applying Adaptive Control began in the early seventies. The growing availability of digital computers have also contributed to the development of the field. The earlier applications provided important feedback for the development of the field. Theoretical developments allowed a number of basic problems to be solved.

The aim of this book is to provide a coherent and comprehensive treatment of the field. The presentation takes the reader from the basic problem formulation to the analytical solutions whose practical significance is illustrated by applications.

A unified presentation of the field of adaptive control is not obvious. One reason for this is that adaptive control involves several design steps, which potentially increase the degrees of freedom. Another reason is that methods have been proposed with different applications in mind without a clear motivation of the various intermediate design steps. It is our belief, however, that a coherent presentation of the basic adaptive control techniques is now possible.

To reflect the importance of digital computers for the application of adaptive control techniques, the formulation in discrete time of the adaptive control problems and solutions has been adopted.

We try to share with the reader our practical experience concerning the understanding and the soundness of various designs.

Throughout the book, the analytical aspects of synthesis and analysis of various algorithms are emphasized. However this does not mean that they are self-sufficient for solving practical problems, or that ad-hoc modifications of the algorithms are not possible for specific applications. To guide the reader, the book contains various applications of adaptive control techniques. It is however our belief that without a

solid analytical understanding of the adaptation techniques, a user will not be able to creatively apply them to a new and difficult situation.

The book is an outgrowth of several survey papers, tutorials and courses delivered to various audiences (graduate students, practicing engineers, etc...) in various countries and of the research done by the authors in the field (mostly at Laboratoire d'Automatique de Grenoble now Control Dept. of GIPSA-LAB (Institut National Polytechnique de Grenoble/ CNRS,), HEUDYASIC (Université Technologique de Compiègne/CNRS,), CINVESTAV (Mexico), GREYC (Caen), Laboratoire d'Automatique of EPFL (Lausanne)), as well as of the long and rich practical experience of the authors. This new edition in one hand reflects new developments in the field both in terms of techniques and applications and on the other hand it puts in a proper perspective a number of techniques (as the result of the feedback from applications).

Expected Audience

The book is intended as a textbook for graduate students as well as a basic reference for practicing engineers facing the problem of designing adaptive control systems. Control researchers from other areas will find a comprehensive presentation of the field and bridges to various other control design techniques.

About the Content

It is widely accepted that stability analysis in a deterministic environment and convergence analysis in a stochastic environment constitute a basic ground for analysis and design of adaptive control systems and therefore this constitutes the core of the theoretical aspects of the book. Parametric Adaptation Algorithms (PAA) which are present in all adaptive control techniques are considered in greater depth.

Our practical experience has shown that often in the past the basic linear controller designs which constitutes the background for various adaptive control strategies did not take into account the robustness issues. It is therefore possible and necessary to take this issue into account and to improve the robustness of the linear control designs prior to the coupling with one of the adaptation algorithms. The book therefore covers this aspect.

However, robustness in the context of adaptive control also concerns the parameter adaptation algorithms and this issue is addressed in detail. Furthermore, multiple model adaptive control with switching is an illustration of the combination of robust control and adaptive control. This technique is deeply covered in this new edition. In recent years, plant model identification in closed loop operation has become more and more popular as a way of improving the performances of an existing controller. The resulting techniques are directly related to adaptive control and will be discussed in depth.

Adaptive regulation and adaptive feedforward disturbance compensation have emerged as new adaptive control problems with immediate application in active

vibration control and active noise control. These aspects are now covered in this second edition.

The book is organized as follows:

- Chapter 1 provides an introduction to adaptive control and a tutorial presentation of the various techniques involved.
- Chapter 2 presents a brief review of discrete-time linear models for control with emphasis on optimal predictors which are often used throughout the book.
- Chapter 3 is a thorough coverage of parameter adaptation algorithms (PAA) operating in a deterministic environment. Various approaches are presented and then the stability point of view for analysis and design is discussed in detail.
- Chapter 4 is devoted to the analysis of parameter adaptation algorithms in a stochastic environment.
- Chapter 5 discusses recursive plant model identification in open loop which on one hand is an immediate application of the PAA and on the other hand constitutes an unavoidable step in starting an adaptive controller.
- Chapter 6 is devoted to the synthesis of adaptive predictors.
- Chapter 7 covers digital control strategies which are used in adaptive control. One step ahead predictive control and long-range predictive control are presented in a unified manner.
- Chapter 8 discusses the robust digital control design problem and provides techniques for achieving required robustness by shaping the sensitivity functions.
- The digital control techniques can be combined with the recursive plant model identification in closed loop to obtain an adaptive controller. These recursive identification techniques are discussed in Chapter 9.
- The issue of robustification of parameter adaptation algorithm in the context of adaptive control is addressed in Chapter 10.
- For special types of plant model structures and control strategies, appropriate parametrization of the plant model allows direct adjustment of the parameters of the controllers yielding the so called *direct adaptive control schemes*. Direct adaptive control is the subject of Chapter 11.
- Indirect adaptive control which combines in real-time plant model parameter estimation in closed loop with the redesign of the controller is discussed in Chapter 12.
- Multimodel adaptive control with switching, which combines robust control and adaptive control, is discussed in Chapter 13 (new).
- Rejection of unknown disturbances is the objective of adaptive regulation which is the subject of Chapter 14 (new).
- Adaptive feedforward compensation of disturbances is discussed in Chapter 15 (new).
- Chapter 16 is devoted to the practical aspects of implementing adaptive controllers.

Chapters 5, 9, 12, 13, 14, 15 include applications using the techniques presented in these chapters. A number of appendices which summarize important background topics are included.

Problems and simulation exercises are included in most of the chapters.

Pathways through the book

The book was written with the objective of presenting a comprehensive coverage of the field but also with the objective to make the subject accessible to a large audience with different backgrounds and interests. Thus the book can be read and used in different ways.

For those only interested in applications we recommend the following sequence: Chapters: 1, 2, 3 (Sections 3.1 and 3.2), 5 (Sections 5.1, 5.2, 5.7 through 5.9), 7 (Sections 7.1, 7.2, 7.3.1 and 7.3.2), 8 (Sections 8.1, 8.2, 8.3.1), 9 (Sections 9.1, 9.6), 10 (Section 10.1), 11 (Sections 11.1, 11.2), 12 (Sections 12.1 and 12.2.1), 13 (Sections 13.1, 13.2 and 13.4), 14 (Sections 14.1, 14.2, 14.4, 14.7), 15 (Sections 15.1, 15.2 and 15.5) and Chapter 16. Most of the content of Chapters 14 and 15 can also be read just after Chapter 3. The sequence above (till Chapter 15) can also serve as an introductory course in adaptive control.

For a more in-depth study of the field a course should include in addition the following Sections: 3.3, 3.4, 4.1, 4.2, 5.3 through 5.6, 6.1, 6.2, 7.3.3 through 7.7, 8.3 through 8.6, 9.2 through 9.6, 10.2, 10.3, 10.4, 10.6, 11.4.1, 11.4.2 and 11.6, 12.2.2 through 12.3.1, 12.4 and 12.7, 13.3, 14.3, 14.5, 15.3 and 15.4. A graduate course in adaptive control might include all chapters of the book.

The material has been organized such that bypasses around the more technical parts of the book can be taken in an obvious way by the reader. Figure P.1 shows the logical progression of the chapters.

The Website

Complementary information and material for teaching and applications can be found on the book website: [http:// www.landau-adaptivecontrol.org](http://www.landau-adaptivecontrol.org)

Acknowledgments

We wish to acknowledge the large number of contributors on whose work our presentation is partly based. In particular, we wish to mention: G. Zames, V.M. Popov, L. Ljung, G. Goodwin, D. Clarke, K.J. Aström, B.D.O. Anderson, A.S. Morse, P. Kokotovic from whom we learned many things.

In our research activity we had the privilege of interacting with a number of colleagues among whom we would like to mention: M. Tomizuka, R. Bitmead, M. Gevers, C.R. Johnson, H.M. Silveira, C. Samson, L. Praly, R. Ortega, Ph. de Larmminat, K. Najim, E. Irving, F. Giri, B. Egardt, L. Dugard, J.M. Dion, B. Brogliato, G. Béthoux, B. Courtiol, H. Duong, A. Besançon and H. Prochazka. We would like to express our appreciation for their contributions.

The long term support of the Centre National de la Recherche Scientifique (CNRS) and of the Institut National Polytechnique de Grenoble is gratefully acknowledged.

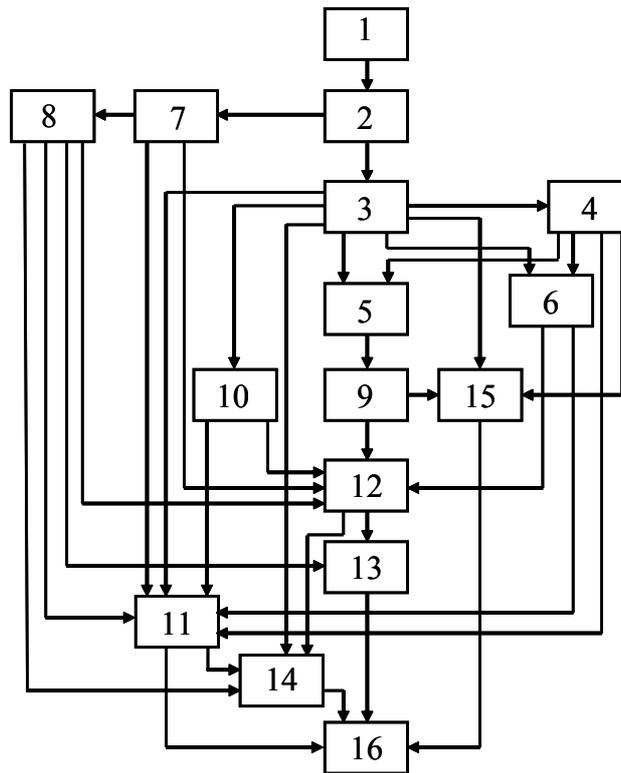


Fig. P.1: Logical dependence of the chapters

We would like to thank J. Langer, A. Constantinescu, J. Chebassier and M. Alma for their effective contribution to this project.

This second edition has also been made possible by Stéphane Mocanu who succeed to find the “lost” electronic files of the first edition.

We would also like to thank Oliver Jackson from Springer Verlag whose enthusiasm and professionalism has helped us to finalize this new edition of the book.

Writing takes a lot of time and most of the writing has been done on overtime. We would like to thank our families for their patience.

Ioan Doré Landau
 Rogelio Lozano
 Mohammed M'Saad
 Alireza Karimi

ioan-dore.landau@gipsa-lab.grenoble-inp.fr
 Rogelio.Lozano@hds.utc.fr
 msaad@greyc.ensicaen.fr
 alireza.karimi@epfl.ch

Grenoble, November 2010