Preface

Adaptive control evolved over the years to become an accepted subject taught in many schools as an advanced control course. A good understanding of adaptive control involves a good knowledge of control design for linear time-invariant systems, basic stability theory of nonlinear systems, and some mathematical maturity. Several books and research monographs as well as numerous papers on the theory and application of adaptive control already exist. Despite the maturity of the field and the numerous publications, the field of adaptive control appears to many as a collection of unrelated techniques, intelligent tricks, and fixes, and very few researchers can really follow the long and technical stability proofs. On the implementation side, designing stable adaptive control systems and simulating them on a digital computer to demonstrate their theoretical properties could also be an adventure if one does not have a good understanding of the basic theoretical properties and limitations of adaptive control.

The purpose of this book is to present the fundamental techniques and algorithms in adaptive control in a tutorial manner making it suitable as an adaptive control textbook. The aim of the book is to serve a wider audience by addressing three classes of readers. The first class includes the readers who are simply interested to learn how to design, simulate, and implement parameter estimators and adaptive control schemes without having to fully understand the analytical and technical proofs. This class may include practicing engineers and students whose background may not be strong enough to follow proofs or who simply like to focus on the application of adaptive control. The second class involves readers who, in addition to learning how to design and implement adaptive systems, are also interested in understanding the analysis of the simple schemes and getting an idea of the steps followed in the more complex proofs. This class of readers may include the majority of students at the Masters and Ph.D. level who take adaptive control as an advanced course. The third class of readers involves the advanced students and researchers who want to study and understand the details of the long and technical proofs as training for pursuing research in adaptive control or in related topics such as nonlinear systems, etc. All of these readers may be found in the same adaptive control class consisting of students with different abilities and interests. The book is written with the objective of at least satisfying the first class of readers irrespective of how strong their theoretical background is, and at the same time serving the needs of the advanced research students on the other end without sacrificing mathematical depth and rigor. These multiple objectives and learning expectations are achieved by enriching the book with examples demonstrating the design procedures and basic analysis steps and presenting the details of the long and technical proofs in an appendix and in electronically available supplementary material. Electronically available also are additional examples and

simulations using the Adaptive Control Toolbox developed by the authors, which readers can purchase separately by contacting the authors.

The material in the book is based on twenty years of experience in teaching adaptive control at the University of Southern California by the first author and on feedback from students and instructors in other universities who taught adaptive control. Our experience taught us that expecting all students to be able to understand and reproduce all technical proofs over one semester is an unrealistic goal and could often lead to confusion. The book is written in a way that allows the teacher to start from the lowest objective of teaching students how to design and simulate adaptive systems and understand their properties, and add more analysis and proofs depending on the level of the course and quality and ambition of the students involved.

The book is organized as follows. Chapter 1 presents some basic characteristics of adaptive systems and a brief history of how adaptive control evolved over the years. Chapter 2 presents the various parameterizations of plants that are suitable for parameter estimation. This is a fairly easy chapter but very important, since in subsequent chapters the expression of the unknown parameters in a parametric model suitable for estimation is the first design step in the development of parameter estimators. The design of parameter estimators or adaptive laws for continuous-time plants is presented in Chapter 3. In Chapter 4 it is shown how the continuous-time estimators developed in Chapter 3 can be discretized using Euler's method of approximating a derivative and still maintain the desired stability properties. In addition, discrete-time parameter estimators are also developed using discrete-time models of the plant. This chapter, for the first time, shows clearly the connection between continuous-time and discrete-time parameter estimators, which until now have been viewed as two completely different methodologies. The design and analysis of a class of adaptive controllers referred to as model reference adaptive control (MRAC), which has been popular in continuous-time adaptive systems, is presented in Chapter 5. Chapter 6 presents the design and analysis of adaptive pole placement (APPC) schemes, which do not require the restrictive assumptions used in the MRAC, as the control objectives are different. The discrete version of the schemes in Chapters 5 and 6 are presented in Chapter 7. In Chapters 3 to 7, the robustness of the schemes developed with respect to bounded external disturbances and dynamic uncertainties is also analyzed, and modifications are presented to enhance robustness. Finally, Chapter 8 gives a brief review, using simple examples, of the extensions of the adaptive systems developed in previous chapters to classes of nonlinear systems with unknown parameters. All mathematical preliminaries that are useful for the chapters are presented in the Appendix. The reader may go over the Appendix first before reading the chapters, as certain concepts and results presented in the Appendix are often quoted and used. Long proofs and supplementary material as well as additional examples and simulations using the Adaptive Control Toolbox are available in electronic form at http://www.siam.org/books/dc11. A solution manual is also available to instructors who can verify that they teach a class on adaptive systems using this book as textbook, by contacting the publisher or the authors.