Preface

The aim of this work is to provide an introduction to the basic definitions and tools for the application of fractional calculus in automatic control. It is intended to serve the control community as a guide to understanding and using fractional calculus in order to enlarge the application domains of its disciplines, and to improve and generalize well established control methods and strategies. A major goal of this book is to present a concise and insightful view of the current knowledge on fractional-order control by emphasizing fundamental concepts, giving the basic tools to understand why fractional calculus is useful in control, to understand its terminology, and to illuminate the key points of its applicability.

Fractional calculus can be defined as the generalization of classical calculus to orders of integration and differentiation not necessarily integer. Though the concepts of non-integer-order operators are by no means new, the first meeting devoted to the topic took place in 1974, in New Haven, Connecticut, USA. Even at such an event, fractional calculus was a matter of almost exclusive interest for few mathematicians and theoretical physicists. However, circumstances have changed considerably since then. On the one hand, in the last 3 decades the general interest in such a tool has experienced a continuing growth, and at present we can find many conferences, symposia, workshops, or special sessions, as well as papers and special issues in recognized journals, devoted to the theoretical and application aspects of fractional calculus. On the other hand, as can be observed in such conferences and journals, motivation for this growing interest has been the engineering applications, especially the control engineering ones.

Control is an interdisciplinary branch of engineering and mathematics that deals with the modification of dynamic systems to obtain a desired behavior given in terms of a set of specifications or a reference model. To obtain the desired behavior, a designed controller senses the operation of the system, compares it to the desired behavior, computes corrective actions based on specifications or reference models, and actuates the system to obtain the desired change. So, in order that the dynamics of a system or process might be properly modified, we need a model of the system, tools for its analysis, ways to specify the required behavior, methods to design the controller, and techniques to implement them. Since the usual tools to model dynamic systems at a macroscopic level are integrals and derivatives, at least in the linear systems case, the algorithms that implement the controllers are mainly composed of such tools. So, it is not hard to understand that a way to extend the definitions of integrals and derivatives can provide a way to expand the frontiers for their applicability.

Fractional-order control is the use of fractional calculus in the aforementioned topics, the system being modeled in a classical way or as a fractional one. From a certain point of view, the applications of fractional calculus have experienced an evolution analogous to that of control, following two parallel paths depending on the starting point: the time domain or the frequency domain. Whilst the applications in dynamic systems modeling have used, except in some cases of electrochemistry, the time domain, the applications in control have been developed, mainly and from the very beginning, in the frequency domain.

It is our hope that this book will be read by, and of interest to, a wide audience. For this reason, it is organized following the structure of a traditional textbook in control. Therefore, in Part I, after the introduction in Chapter 1, Chapter 2 gives the fundamental definitions of fractional calculus, having in mind our goal of providing a stimulating introduction for the control community. Therefore, the mathematical prerequisites have been kept to a minimum (those used in a basic course of control: linear algebra, including matrices, vectors, and eigenvalues; classical calculus, including differential equations and concepts of homogeneous and particular solutions; complex numbers, functions, and variables; and integral transforms of Laplace and Fourier), avoiding unnecessary intricate mathematical considerations but without an essential loss of rigor. Chapter 3 is devoted to state-space representations and analysis of fractional-order systems, completing the fundamental definitions given in Chapter 2. Chapter 4 is a detailed exposition of the core concepts and tools for the useful application of fractional calculus to control, based on the generalization of the basic control actions. In Part II, there is a complete study of fractional-order PID controllers, dealing with definitions, tuning methods, and real application examples given in Chapters 5–7. Part III focuses on the generalization of the standard lead-lag compensator. Chapter 8 presents an effective tuning method for the fractional-order lead-lag compensator (FOLLC), and Chapter 9 proposes a simple and direct auto-tuning technique for this type of structure. Part IV provides an overview of other fractional-order control strategies, showing their achievements and analyzing the challenges for further work. Chapter 10 reviews some important fractional-order robust control techniques, such as CRONE and QFT. Chapter 11 presents some nonlinear fractional-order control strategies. Part V provides methods and tools for the implementation of fractional-order controllers. Chapter 12 deals with continuous- and discrete-time implementations of these types of controllers and Chapter 13 with numerical issues and MATLAB implementations. Finally, Part VI is devoted to real applications of fractional-order systems and controls. The identification problem of an electrochemical process and a flexible structure is presented in Chapter 14; the position control of a single-link flexible robot in Chapter 15; the automatic control of a hydraulic canal in Chapter 16; mechatronic applications in Chapter 17; and fractional-order control strategies for power electronic buck converters in Chapter 18. In the Appendix, additional useful information is given, such as Laplace transform tables involving fractional-order operators.

We would like to thank Professor (Emeritus) Michael A. Johnson and Professor Michael J. Grimble, Series Editors of Advances in Industrial Control Monograph Series of Springer London. Without their invitation, encouragement, and wise recommendations and comments, this book project would not have been possible. Thanks are also due to Oliver Jackson and his Editorial Assistants for Engineering, Ms. Aislinn Bunning and Ms. Charlotte Cross of Springer London, who have helped us through the review, copy-editing, and production process with care and professional support.

We would also like to acknowledge the collaborations of Prof. Igor Podlubny, Prof. Ivo Petráš, Prof. Richard Magin, Prof. Hongsheng Li, Dr. Gary Bohannan, Prof. Kevin L. Moore, Dr. Hyo-Sung Ahn, Dr. Jun-Guo Lu, Dr. Larry Ying Luo, Prof. Yan Li, Dr. Chunna Zhao, Dr. Antonio J. Calderón, Dr. Inés Tejado, Dr. Fernando J. Castillo, Dr. Francisco Ramos, Prof. Raúl Rivas, and Prof. Luis Sánchez.

Last but not least, we wish to thank the small but growing community of researchers on fractional calculus and its applications. We acknowledge the benefits we have obtained from interacting with this open-minded community in the past years.

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January 2010

http://www.springer.com/978-1-84996-334-3

Fractional-order Systems and Controls
Fundamentals and Applications
Monje, C.A.; Chen, Y.; Vinagre, B.M.; Xue, D.; Feliu-Batlle, V.
2010, XVI, 415 p. With online files/update., Hardcover
ISBN: 978-1-84996-334-3