Fractional Order Systems Modeling And Control Applications World Scientific Series On Nonlinear Science Series A

This book introduces an original fractional calculus methodology (the infinite state approach) which is applied to the modeling of fractional order differential equations (FDEs) and systems (FDSs). Its modeling is based on the frequency distributed fractional integrator, while the resulting model corresponds to an integer order and infinite dimension state space representation. This original modeling allows the theoretical concepts of integer order systems to be generalized to fractional systems, with a particular emphasis on a convolution formulation. With this approach, fundamental issues such as system state interpretation and system initialization – long considered to be major theoretical pitfalls – have been solved easily. Although originally introduced for numerical simulation and identification of FDEs, this approach also provides original solutions to many problems such as the initial conditions of fractional derivatives, the uniqueness of FDS transients, formulation of analytical transients, fractional differentiation of functions, state observation and control, definition of fractional energy, and Lyapunov stability analysis of linear and nonlinear fractional order systems. This second volume focuses on the initialization, observation and control of the distributed state, followed by stability analysis of fractional differential systems.

Fractional-order Systems and Controls details the use of fractional calculus in the description and modeling of systems, and in a range of control design and practical applications. It is largely self-contained, covering the fundamentals of fractional calculus together with some analytical and numerical techniques and providing MATLAB® codes for the simulation of fractional-order control (FOC) systems. Many different FOC schemes are presented for control and dynamic systems problems. Practical material relating to a wide variety of applications is also provided. All the control schemes and applications are presented in the monograph with either system simulation results or real experimental results, or both. Fractional-order Systems and Controls provides readers with a basic understanding of FOC concepts and methods, so they can extend their use of FOC in other industrial system applications, thereby expanding their range of disciplines by exploiting this versatile new set of control techniques.

This book reports on an outstanding research devoted to modeling and control of dynamic systems using fractional-order calculus. It describes the development of model-based control design methods for systems described by fractional dynamic models. More than 300 years had passed since Newton and Leibniz developed a set of mathematical tools we now know as calculus. Ever since then the idea of non-integer derivatives and integrals, universally referred to as fractional calculus, has been of interest to many researchers. However, due to various issues, the usage of fractional-order models in real-life applications was limited. Advances in modern computer science made it possible to apply efficient numerical methods to the computation of fractional derivatives and integrals. This book describes novel methods developed by the author for fractional modeling and control, together with their successful application in real-world process control scenarios.

In the recent years, fractional-order systems have been studied by many researchers in the engineering field. It was found that many systems can be described more accurately by fractional differential equations than by integer-order models. Advanced Synchronization Control and Bifurcation of Chaotic Fractional-Order Systems is a scholarly publication that explores new developments related to novel chaotic fractional-order systems, control schemes, and their applications. Featuring coverage on a wide range of topics including chaos synchronization, nonlinear control, and cryptography, this publication is geared toward engineers, IT professionals, researchers, and upper-level graduate students seeking current research on chaotic fractional-order systems and their applications in engineering and computer science.

This book provides an overview of some recent findings in the theory and applications of non-integer order systems. Discussing topics ranging from the mathematical foundations to technical applications of continuous-time and discrete-time fractional calculus, it includes 22 original research papers and is subdivided into four parts: • Mathematical Foundations • Approximation, Modeling and Simulations • Fractional Systems Analysis and Control • Applications The papers were selected from those presented at the 10th International Conference of Non-integer Order Calculus and its Applications, which was held at the Bialystok University of Technology, Poland, September 20–21, 2018. Thanks to the broad spectrum of topics covered, the book is suitable for researchers from applied mathematics and engineering. It is also a valuable resource for graduate students, as well as for scholars looking for new mathematical tools.

Distributed-order differential equations, a generalization of fractional calculus, are of increasing importance in many fields of science and engineering from the behaviour of complex dielectric media to the modelling of nonlinear systems. This Brief will broaden the toolbox available to researchers interested in modeling, analysis, control and filtering. It contains contextual material outlining the progression from integer-order, through fractional-order to distributed-order systems. Stability issues are addressed with graphical and numerical results highlighting the fundamental differences between constant-, integer-, and distributed-order treatments. The power of the distributed-order model is demonstrated with work on the stability of noncommensurate-order linear time-invariant systems. Generic applications of the distributed-order operator follow: signal processing and viscoelastic damping of a mass–spring set up. A new general approach to discretization of distributed-order derivatives and integrals is described. The Brief is rounded out with a consideration of likely future research and applications and with a number of MATLAB® codes to reduce repetitive coding tasks and encourage new workers in distributed-order systems.

Fractional order calculus is finding increasing interest in the control system community. Hardware realizations of fractional order controllers have sparked off a renewed zeal into the investigations of control system design in the light of fractional calculus. As such many notions of integer order LTI systems are being modified and extended to incorporate these new concepts. Computational Intelligence (CI) techniques have been applied to engineering problems to find solutions to many hitherto intractable conundrums and is a useful tool for dealing with problems of higher computational complexity. This book borders on the interface between CI techniques and fractional calculus, and looks at ways in which fractional order control systems may be designed

or enhanced using CI based paradigms. To the best of the author's knowledge this is the first book of its kind exclusively dedicated to the application of computational intelligence techniques in fractional order systems and control. The book tries to assimilate various existing concepts in this nascent field of fractional order intelligent control and is aimed at researchers and post graduate students working in this field.
This book focuses on fractional calculus, presenting novel advances in both the theory and applications of non-integer order systems. At the end of the twentieth century it was predicted that it would be the calculus of the twenty-first century, and that prophecy is confirmed year after year. Now this mathematical tool is successfully used in a variety of research areas, like engineering (e.g. electrical, mechanical, chemical), dynamical systems modeling, analysis and synthesis (e.g technical, biological, economical) as well as in multidisciplinary areas (e.g. biochemistry, electrochemistry).As well as the mathematical foundations the book concentrates on the technical applications of continuous-time and discrete-time fractional calculus, investigating the identification, analysis and control of electrical circuits and dynamical systems. It also presents the latest results.Although some scientific centers and scientists are skeptical and actively criticize the applicability of fractional calculus, it is worth breaking through the scientific and technological walls. Because the “fractional community” is growing rapidly there is a pressing need for the exchange of scientific results. The book includes papers presented at the 9th International Conference on Non-integer Order Calculus and Its Applications and is divided into three parts:• Mathematical foundations• Fractional systems analysis and synthesis• System modelingSeven papers discuss the mathematical foundations, twelve papers address fractional order analysis and synthesis and three focus on dynamical system modeling by the fractional order differential and difference equations. It is a useful resource for fractional calculus scientific community.

Fractional Order SystemsModeling and Control ApplicationsWorld Scientific

This book illustrates the application of fractional calculus in crowd dynamics via modeling and control groups of pedestrians. Decision-making processes, conservation laws of mass/momentum, and micro-macro models are employed to describe system dynamics while cooperative movements in micro scale, and fractional diffusion in macro scale are studied to control the group of pedestrians. Obtained work is included in the Intelligent Evacuation Systems that is used for modeling and to control crowds of pedestrians. With practical issues considered, this book is of interests to mathematicians, physicists, and engineers.

In the last two decades fractional differential equations have been used more frequently in physics, signal processing, fluid mechanics, viscoelasticity, mathematical biology, electro chemistry and many others. It opens a new and more realistic way to capture memory dependent phenomena and irregularities inside the systems by using more sophisticated mathematical analysis. This monograph is based on the authors' work on stabilization and control design for continuous and discrete fractional order systems. The initial two chapters and some parts of the third chapter are written in tutorial fashion, presenting all the basic concepts of fractional order system and a brief overview of sliding mode control of fractional order systems. The other parts contain deal with robust finite time stability of fractional order systems, integral sliding mode control of fractional order systems, co-operative control of multi-agent systems modeled as fractional differential equation, robust stabilization of discrete fractional order systems, high performance control using soft variable structure control and contraction analysis by integer and fractional order infinitesimal variations.

This book at hand is an appropriate addition to the field of fractional calculus applied to control systems. If an engineer or a researcher wishes to delve into fractional-order systems, then this book has many collections of such systems to work upon, and this book also tells the reader about how one can convert an integer-order system into an appropriate fractional-order one through an efficient and simple algorithm. If the reader further wants to explore the controller design for the fractional-order systems, then for them, this book provides a variety of controller design strategies. The use of fractional-order derivatives and integrals in control theory leads to better results than integer-order approaches and hence provides solid motivation for further development of control theory. Fractional-order models are more useful than the integer-order models when accuracy is of paramount importance. Real-time experimental validation of controller design strategies for the fractional-order plants is available. This book is beneficial to the academic institutes for postgraduate and advanced research-level that need a specific textbook on fractional control and its applications in srobotic manipulators. The book is also a valuable teaching and learning resource for undergraduate and postgraduate students.

This book unites two fast-developing forms of control—vision-based control and fractional-order control—and applies them in mechatronic systems. Image-Based and Fractional-Order Control for Mechatronic Systems is presented in two parts covering the theory and applications of the subject matter. The theoretical material presents the concepts of visual servoing and image-based feature extraction for feedback loops and fractional-order control. It discusses a range of systems from the classic monocular camera to new RGB-D sensors. The applications part of the book first discusses practical issues with the implementation of fractional-order control, comparing them with more traditional integer-order PID systems. The authors then introduce real-life examples such as a manipulator robot and a Stewart platform and results generated from such systems. MATLAB® functions and source codes are included wherever relevant to help readers develop simulations based on the theoretical ideas and practical examples in the text. Suggestions for the use of other pertinent open-source software are also indicated with the places where such may be obtained. With its combination of theoretical ideas and practical examples, Image-Based and Fractional-Order Control for Mechatronic Systems will be of interest to academic researchers looking to develop the fields of vision-based and fractional-order control and to engineers who are looking for developments that will help them provide closer control of their plants than can be achieved with integer-order PID. Advances in Industrial Control reports and encourages the transfer of technology in control engineering. The rapid development of control technology has an impact on all areas of the control discipline. The series offers an opportunity for researchers to present an extended exposition of new work in all aspects of industrial control.

This book is about algebraic and differential methods, as well as fractional calculus, applied to diagnose and reject faults in nonlinear systems, which are of integer or fractional order. This represents an extension of a very important and widely studied problem in control theory, namely fault diagnosis and rejection (using differential algebraic approaches), to systems presenting fractional dynamics, i.e. systems whose dynamics are represented by derivatives and integrals of non-integer order. The authors offer a thorough overview devoted to fault diagnosis and fault-tolerant control applied to fractional-order and integer-order dynamical systems, and they introduce new methodologies for control and observation described by fractional and integer models, together with successful simulations and real-time applications. The basic concepts and tools of mathematics required to understand the methodologies proposed are all clearly introduced and explained. Consequently, the book is useful as supplementary reading in courses of applied mathematics and nonlinear control theory. This book is meant for engineers, mathematicians, physicists and, in general, to researchers and postgraduate students in diverse areas who have a minimum knowledge of calculus. It also contains advanced topics for researchers and professionals interested in the area of states and faults estimation.

This book presents applications of Newton-like and other similar methods to solve abstract functional equations involving fractional derivatives. It focuses on Banach space-valued functions of a real domain – studied for the first time in the literature. Various issues related to the modeling and analysis of fractional order systems continue to grow in popularity, and the book provides a deeper and more formal analysis of selected issues that are relevant to many areas – including decision-making, complex processes, systems modeling and control – and deeply embedded in the fields of engineering, computer science, physics, economics, and the social and life sciences. The book offers a valuable resource for researchers and graduate students, and can also be used as a textbook for seminars on the above-mentioned subjects. All chapters are self-contained and can be read independently. Further, each chapter includes an extensive list of references.

The book reports on the latest advances in and applications of fractional order control and synchronization of chaotic systems, explaining the concepts involved in a clear, matter-of-fact style. It consists of 30 original contributions written by eminent scientists and active researchers in the field that address theories, methods and applications in a number of research areas related to fractional order control and synchronization of chaotic systems, such as: fractional chaotic systems, hyperchaotic systems, complex systems, fractional order discrete chaotic systems, chaos control, chaos synchronization, jerk circuits, fractional

chaotic systems with hidden attractors, neural network, fuzzy logic controllers, behavioral modeling, robust and adaptive control, sliding mode control, different types of synchronization, circuit realization of chaotic systems, etc. In addition to providing readers extensive information on chaos fundamentals, fractional calculus, fractional differential equations, fractional control and stability, the book also discusses key applications of fractional order chaotic systems, as well as multidisciplinary solutions developed via control modeling. As such, it offers the perfect reference guide for graduate students, researchers and practitioners in the areas of fractional order control systems and fractional order chaotic systems.
This book provides a general overview of several concepts of synchronization and brings together related approaches to secure communication in chaotic systems. This is achieved using a combination of analytic, algebraic, geometrical and asymptotical methods to tackle the dynamical feedback stabilization problem. In particular, differential-geometric and algebraic differential concepts reveal important structural properties of chaotic systems and serve as guide for the construction of design procedures for a wide variety of chaotic systems. The basic differential algebraic and geometric concepts are presented in the first few chapters in a novel way as design tools, together with selected experimental studies demonstrating their importance. The subsequent chapters treat recent applications. Written for graduate students in applied physical sciences, systems engineers, and applied mathematicians interested in synchronization of chaotic systems and in secure communications, this self-contained text requires only basic knowledge of integer ordinary and fractional ordinary differential equations. Design applications are illustrated with the help of several physical models of practical interest.
Fractional-order Modelling of Dynamic Systems with Applications in Optimization, Signal Processing and Control introduces applications from a design perspective, helping readers plan and design their own applications. The book includes the different techniques employed to design fractional-order systems/devices comprehensively and straightforwardly. Furthermore, mathematics is available in the literature on how to solve fractional-order calculus for system applications. This book introduces the mathematics that has been employed explicitly for fractional-order systems. It will prove an excellent material for students and scholars who want to quickly understand the field of fractional-order systems and contribute to its different domains and applications. Fractional-order systems are believed to play an essential role in our day-to-day activities. Therefore, several researchers around the globe endeavor to work in the different domains of fractional-order systems. The efforts include developing the mathematics to solve fractional-order calculus/systems and to achieve the feasible designs for various applications of fractional-order systems. Presents a simple and comprehensive understanding of the field of fractional-order systems Offers practical knowledge on the design of fractional-order systems for different applications Exposes users to possible new applications for fractional-order systems

"Fractional-Order Nonlinear Systems: Modeling, Analysis and Simulation" presents a study of fractional-order chaotic systems accompanied by Matlab programs for simulating their state space trajectories, which are shown in the illustrations in the book. Description of the chaotic systems is clearly presented and their analysis and numerical solution are done in an easy-to-follow manner. Simulink models for the selected fractional-order systems are also presented. The readers will understand the fundamentals of the fractional calculus, how real dynamical systems can be described using fractional derivatives and fractional differential equations, how such equations can be solved, and how to simulate and explore chaotic systems of fractional order. The book addresses to mathematicians, physicists, engineers, and other scientists interested in chaos phenomena or in fractional-order systems. It can be used in courses on dynamical systems, control theory, and applied mathematics at graduate or postgraduate level. Ivo Petráš is an Associate Professor of automatic control and the Director of the Institute of Control and Informatization of Production Processes, Faculty of BERG, Technical University of Košice, Slovak Republic. His main research interests include control systems, industrial automation, and applied mathematics.

Fractional Dynamics and Control provides a comprehensive overview of recent advances in the areas of nonlinear dynamics, vibration and control with analytical, numerical, and experimental results. This book provides an overview of recent discoveries in fractional control, delves into fractional variational principles and differential equations, and applies advanced techniques in fractional calculus to solving complicated mathematical and physical problems.Finally, this book also discusses the role that fractional order modeling can play in complex systems for engineering and science.

Fractional processes are widely found in science, technology and engineering systems. In Fractional Processes and Fractional-order Signal Processing, some complex random signals, characterized by the presence of a heavy-tailed distribution or non-negligible dependence between distant observations (local and long memory), are introduced and examined from the 'fractional' perspective using simulation, fractional-order modeling and filtering and realization of fractional-order systems. These fractional-order signal processing (FOSP) techniques are based on fractional calculus, the fractional Fourier transform and fractional lower-order moments. Fractional Processes and Fractional-order Signal Processing: presents fractional processes of fixed, variable and distributed order studied as the output of fractional-order differential systems; introduces FOSP techniques and the fractional signals and fractional systems point of view; details real-world-application examples of FOSP techniques to demonstrate their utility; and provides important background material on Mittag–Leffler functions, the use of numerical inverse Laplace transform algorithms and supporting MATLAB® codes together with a helpful survey of relevant webpages. Readers will be able to use the techniques presented to re-examine their signals and signal-processing methods. This text offers an extended toolbox for complex signals from diverse fields in science and engineering. It will give academic researchers and practitioners a novel insight into the complex random signals characterized by fractional properties, and some powerful tools to analyze those signals.

Fractional calculus provides the possibility of introducing integrals and derivatives of an arbitrary order in the mathematical modelling of physical processes, and it has become a relevant subject with applications to various fields, such as anomalous diffusion, propagation in different media, and propogation in relation to materials with different properties. However, many aspects from theoretical and practical points of view have still to be developed in relation to models based on fractional operators. This Special Issue is related to new developments on different aspects of fractional differential equations, both from a theoretical point of view and in terms of applications in different fields such as physics, chemistry, or control theory, for instance. The topics of the Issue include fractional calculus, the mathematical analysis of the properties of the solutions to fractional equations, the extension of classical approaches, or applications of fractional equations to several fields.

Mathematical Techniques of Fractional Order Systems illustrates advances in linear and nonlinear fractional-order systems relating to many interdisciplinary applications, including biomedical, control, circuits, electromagnetics and security. The book covers the mathematical background and literature survey of fractional-order calculus and generalized fractional-order circuit theorems from different perspectives in design, analysis and realizations, nonlinear fractional-order circuits and systems, the fractional-order memristive circuits and systems in design, analysis, emulators, simulation and experimental results. It is primarily meant for researchers from academia and industry, and for those working in areas such as control engineering, electrical engineering, computer science and information technology. This book is ideal for researchers working in the area of both continuous-time and discrete-time dynamics and chaotic systems.

Discusses multidisciplinary applications with new fundamentals, modeling, analysis, design, realization and experimental results Includes circuits and systems based on new nonlinear elements Covers most of the linear and nonlinear fractional-order theorems that will solve many scientific issues for researchers Closes the gap between theoretical approaches and real-world applications Provides MATLAB® and Simulink code for many applications in the book

The book tries to briefly introduce the diverse literatures in the field of fractional order signal processing which is becoming an emerging topic among an interdisciplinary community of researchers. This book is aimed at postgraduate and beginning level research scholars who would like to work in the field of Fractional Order Signal processing (FOSP). The readers should have preliminary knowledge about basic signal processing techniques. Prerequisite knowledge of fractional calculus is not essential and is exposited at relevant places in connection to the appropriate signal processing topics. Basic signal processing techniques like filtering, estimation, system identification, etc. in the light of fractional order calculus are presented along with relevant application areas. The readers can easily extend these concepts to varied disciplines like image or speech processing, pattern recognition, time series forecasting, financial data analysis and modeling, traffic modeling in communication channels, optics, biomedical signal processing, electrochemical applications and many more. Adequate references are provided in each category so that the researchers can delve deeper into each area and broaden their horizon of understanding. Available MATLAB tools to simulate FOSP theories are also introduced so that the readers can apply the theoretical concepts right-away and gain practical insight in the specific domain.

This book aims to propose implementations and applications of Fractional Order Systems (FOS). It is well known that FOS can be applied in control applications and systems modeling, and their effectiveness has been proven in many theoretical works and simulation routines. A further and mandatory step for FOS real world utilization is their hardware implementation and applications on real systems modeling. With this viewpoint, introductive chapters on FOS are included, on the definition of stability region of Fractional Order PID Controller and Chaotic FOS, followed by the practical implementation based on Microcontroller, Field Programmable Gate Array, Field Programmable Analog Array and Switched Capacitor. Another section is dedicated to FO modeling of Ionic Polymeric Metal Composite (IPMC). This new material may have applications in robotics, aerospace and biomedicine.

This book introduces an original fractional calculus methodology ('the infinite state approach') which is applied to the modeling of fractional order differential equations (FDEs) and systems (FDSs). Its modeling is based on the frequency distributed fractional integrator, while the resulting model corresponds to an integer order and infinite dimension state space representation. This original modeling allows the theoretical concepts of integer order systems to be generalized to fractional systems, with a particular emphasis on a convolution formulation.

This book presents a detailed study on fractional-order, set-point, weighted PID control strategies and the development of curve-fitting-based approximation techniques for fractional-order parameters. Furthermore, in all the cases, it includes the Scilab-based commands and functions for easy implementation and better understanding, and to appeal to a wide range of readers working with the software. The presented Scilab-based toolbox is the first toolbox for fractional-order systems developed in open-source software. The toolboxes allow time and frequency domains as well as stability analysis of the fractional-order systems and controllers. The book also provides real-time examples of the control of process plants using the developed fractional-order based PID control strategies and the approximation techniques. The book is of interest to readers in the areas of fractional-order controllers, approximation techniques, process modeling, control, and optimization, both in industry and academia. In industry, the book is particularly valuable in the areas of research and development (R&D) as well as areas where PID controllers suffice – and it should be noted that around 80% of low-level controllers in industry are PID based. The book is also useful where conventional PIDs are constrained, such as in industries where long-term delay and non-linearity are present. Here it can be used for the design of controllers for real-time processes. The book is also a valuable teaching and learning resource for undergraduate and postgraduate students.

This volume presents selected aspects of non-integer, or fractional order systems, whose analysis, synthesis and applications have increasingly become a real challenge for various research communities, ranging from science to engineering. The spectrum of applications of the fractional order calculus has incredibly expanded, in fact it would be hard to find a science/engineering-related subject area where the fractional calculus had not been incorporated. The content of the fractional calculus is ranged from pure mathematics to engineering implementations and so is the content of this volume. The volume is subdivided into six parts, reflecting particular aspects of the fractional order calculus. The first part contains a single invited paper on a new formulation of fractional-order descriptor observers for fractional-order descriptor continous LTI systems. The second part provides new elements to the mathematical theory of fractional-order systems. In the third part of this volume, a bunch of new results in approximation, modeling and simulations of fractional-order systems is given. The fourth part presents new solutions to some problems in controllability and control of non-integer order systems, in particular fractional PID-like control. The fifth part analyzes the stability of non-integer order systems and some new results are offered in this important respect, in particular for discrete-time systems. The final, sixth part of this volume presents a spectrum of applications of the noninteger order calculus, ranging from bi-fractional filtering, in particular of electromyographic signals, through the thermal diffusion and advection diffusion processes to the SIEMENS platform implementation. This volume's papers were all subjected to stimulating comments and discussions from the active audience of the RRNR'2014, the 6th Conference on Non-integer Order Calculus and Its Applications that was organized by the Department of Electrical, Control and Computer Engineering, Opole University of Technology, Opole, Poland.

This is the first book that uses Artificial Neural Networks (ANN) to solve fractional order systems. As a powerful data modeling tool, information is processed through neurons in parallel manner to solve a specific problem. Knowledge is acquired through learning and stored with inter neuron connections strength which are expressed by numerical values called weights. These weights are used to complete output signal values for new testing input signal value.In this book, multi-layer ANN model will be used to handle fractional order differential equations (FDEs). The network is trained using a back-propagation unsupervised learning algorithm which is based on the gradient descent rule. The ANN approximate solution of FDEs may be expressed as a sum of two terms; the first part satisfies boundary or initial conditions, and the second term contains ANN output with network parameters (weights and biases).Next, single layer Functional Link Artificial Neural Network (FLANN) models will be included for solving the FDEs. In FLANN the hidden layer is replaced by a functional expansion block for enhancement of the input patterns using orthogonal polynomials such as Chebyshev, Legendre, Hermite, etc. The computations become efficient because the procedure does not need to have hidden layer. Thus, the numbers of network parameters are less than the traditional ANN model.Varieties of FDEs will be addressed to show the reliability and efffectiveness of ANN. Singular nonlinear fractional Lane-Emden type equations, fractional vibration problems viz. Bagley-Torvik equations, fractional electrical problems viz. RLC, RC, LC circuit problems, Duffing oscillator problems with fractional derivatives etc. will be handled using multi-layer ANN and single layer FLANN models.

Fractional Order Systems: An Overview of Mathematics, Design, and Applications for Engineers introduces applications from a design perspective, helping readers plan and design their own applications. The book includes the different techniques employed to design fractional-order systems/devices comprehensively and straightforwardly. Furthermore, mathematics is available in the literature on how to solve fractional-order calculus for system applications. This book introduces the mathematics that has been employed explicitly for fractional-order systems. It will prove an excellent material for students and scholars who want to quickly understand the field of fractional-order systems and contribute to its different domains and applications. Fractional-order systems are believed to play an essential role in our day-to-day activities. Therefore, several researchers around the globe endeavor to work in the different domains of fractional-order systems. The efforts include developing the mathematics to solve fractional-order calculus/systems and to achieve the feasible designs for various applications of fractional-order systems. Presents a simple and comprehensive understanding of the field of fractional-order systems Offers practical knowledge on the design of fractional-order systems for different applications Exposes users to possible new applications for fractional-order systems

This book addresses the topic of fractional-order modeling of nuclear reactors. Approaching neutron transport in the reactor core as anomalous diffusion, specifically subdiffusion, it starts with the development of fractional-order neutron telegraph equations. Using a systematic approach, the book then examines the development and analysis of various fractional-order models representing nuclear reactor dynamics, ultimately leading to the fractional-order linear and nonlinear control-oriented models. The book utilizes the mathematical tool of fractional calculus, the calculus of derivatives and integrals with arbitrary non-integer orders (real or complex), which has recently been found to provide a more compact and realistic representation to the dynamics of diverse physical systems. Including extensive simulation results and discussing important issues related to the fractional-order modeling of nuclear reactors, the book offers a valuable resource for students and researchers working in the areas of fractional-order modeling and control and nuclear reactor modeling.

This book explains the essentials of fractional calculus and demonstrates its application in control system modeling, analysis and design. It presents original research to find high-precision solutions to fractional-order differentiations and differential equations. Numerical algorithms and their implementations are proposed to analyze multivariable fractional-order control systems. Through high-quality MATLAB programs, it provides engineers and applied mathematicians with theoretical and numerical tools to design control systems. Contents Introduction to fractional calculus and fractional-order control Mathematical prerequisites Definitions and computation algorithms of fractional-order derivatives and Integrals Solutions of linear fractional-order differential equations Approximation of fractional-order operators Modelling and analysis of multivariable fractional-order transfer function Matrices State space modelling and analysis of linear fractional-order Systems Numerical solutions of nonlinear fractional-order differential Equations Design of fractional-order PID controllers Frequency domain controller design for multivariable fractional-order Systems Inverse Laplace transforms involving fractional and irrational Operations FOTF Toolbox functions and models Benchmark problems for the assessment of fractional-order differential equation algorithms

Fractional Order Systems: Optimization, Control, Circuit Realizations and Applications consists of 21 contributed chapters by subject experts. Chapters offer practical solutions and novel methods for recent research problems in the multidisciplinary applications of fractional order systems, such as FPGA, circuits, memristors, control algorithms, photovoltaic systems, robot manipulators, oscillators, etc. This book is ideal for researchers working in the modeling and applications of both continuous-time and discrete-time dynamics and chaotic systems. Researchers from academia and industry who are working in research areas such as control engineering, electrical engineering, mechanical engineering, computer science, and information technology will find the book most informative. Discusses multi-disciplinary applications with new fundamentals, modeling, analysis, design, realization and experimental results Includes new circuits and systems based on the new nonlinear elements Covers most of the linear and nonlinear fractional-order theorems that will solve many scientific issues for researchers Closes the gap between theoretical approaches and real-world applications Provides MATLAB(R) and Simulink code for many of the applications in the book

A treatise on investigating tracking control and synchronization control of fractional-order nonlinear systems with system uncertainties, external disturbance, and input saturation Robust Adaptive Control for Fractional-Order Systems, with Disturbance and Saturation provides the reader with a good understanding on how to achieve tracking control and synchronization control of fractional-order nonlinear systems with system uncertainties, external disturbance, and input saturation. Although some texts have touched upon control of fractional-order systems, the issues of input saturation and disturbances have rarely been considered together. This book offers chapter coverage of fractional calculus and fractional-order systems; fractional-order PID controller and fractional-order disturbance observer; design of fractional-order controllers for nonlinear chaotic systems and some applications; sliding mode control for fractional-order nonlinear systems based on disturbance observer; disturbance observer based neural control for an uncertain fractional-order rotational mechanical system; adaptive neural tracking control for uncertain fractional-order chaotic systems subject to input saturation and disturbance; stabilization control of continuous-time fractional positive systems based on disturbance observer; sliding mode synchronization control for fractional-order chaotic systems with disturbance; and more. Based on the approximation ability of the neural network (NN), the adaptive neural control schemes are reported for uncertain fractional-order nonlinear systems Covers the disturbance estimation techniques that have been developed to alleviate the restriction faced by traditional feedforward control and reject the effect of external disturbances for uncertain fractional-order nonlinear systems By combining the NN with the disturbance observer, the disturbance observer based adaptive neural control schemes have been studied for uncertain fractional-order nonlinear systems with unknown disturbances Considers, together, the issue of input saturation and the disturbance for the control of fractional-order nonlinear systems in the present of system uncertainty, external disturbance, and input saturation Robust Adaptive Control for Fractional-Order Systems, with Disturbance and Saturation can be used as a reference for the academic research on fractional-order nonlinear systems or used in Ph.D. study of control theory and engineering.

This book is focused on fractional order systems. Historically, fractional calculus has been recognized since the inception of regular calculus, with the first written reference dated in September 1695 in a letter from Leibniz to L'Hospital. Nowadays, fractional calculus has a wide area of applications in areas such as physics, chemistry, bioengineering, chaos theory, control systems engineering, and many others. In all those applications, we deal with fractional order systems in general. Moreover, fractional calculus plays an important role even in complex systems and therefore allows us to develop better descriptions of real-world phenomena. On that basis, fractional order systems are ubiquitous, as the whole real world around us is fractional. Due to this reason, it is urgent to consider almost all systems as fractional order systems. This Special Issue explores applications of such systems to control, synchronization, and various mathematical models, as for instance, MRI, long memory process, diffusion.

After a short introduction to the fundamentals, this book provides a detailed account of major advances in applying fractional calculus to dynamical systems. Fractional order dynamical systems currently continue to gain further importance in many areas of science and engineering. As with many other approaches to mathematical modeling, the first issue to be addressed is the need to couple a definition of the fractional differentiation or integration operator with the types of dynamical systems that are analyzed. As such, for the fundamentals the focus is on basic aspects of fractional calculus, in particular stability analysis, which is required to tackle synchronization in coupled fractional order systems, to understand the essence of estimators for related integer order systems, and to keep track of the interplay between synchronization and parameter observation. This serves as the common basis for the more advanced topics and applications presented in the subsequent chapters, which include an introduction to the 'Immersion and Invariance' (I&I) methodology, the masterslave synchronization scheme for partially known nonlinear fractional order systems, Fractional Algebraic Observability (FAO) and Fractional Generalized quasi-Synchronization (FGqS) to name but a few. This book is intended not only for applied mathematicians and theoretical physicists, but also for anyone in applied science dealing with complex nonlinear systems.

Fractional Order Systems and Applications in Engineering presents the use of fractional calculus (calculus of non-integer order) in the description and modelling of systems and in a range of control design and practical applications. The book covers the fundamentals of fractional calculus together with some analytical and numerical techniques, and provides MATLAB® codes for the simulation of fractional-order control (FOC) systems. The use of fractional calculus can improve and generalize well-established control methods and strategies. Many different FOC schemes are presented for control and dynamic systems problems. These extend to the challenging control engineering design problems of robust and nonlinear control. Practical material relating to a wide variety of applications including, among others, mechatronics, civil engineering, irrigation and water management, and biological systems is also provided. All the control schemes and applications are presented with either system simulation results or real experimental results, or both. Fractional Order Systems and Applications in Engineering introduces readers to the essentials of FOC and imbues them with a basic understanding of FOC concepts and methods. With this knowledge readers can extend their use of FOC in other industrial system applications, thereby expanding their range of disciplines by exploiting this versatile new set of control techniques. Provides the most recent and up-to-date developments on the Fractional-order Systems and their analyzing process Integrates recent advancements of modeling of real phenomena (on Fractional-order Systems) via different-different mathematical equations with demonstrated applications in numerous seemingly diverse and widespread fields of science and engineering Provides readers with illustrative examples of how to use the presented theories of Fractional-order Systems in specific cases with associated MATLAB code