Fractional Differential Equations An Introduction To Fractional Derivatives Fractional Differential Equations To Methods Of Their Solution And Some Mathematics In Science And Engineering | c72fe959f8a5c2822926fec98c1c244

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Applications of Fractional Calculus in Physics
This multi-volume handbook is the most up-to-date and comprehensive reference work in the field of fractional calculus and its numerous applications. This second volume collects authoritative chapters covering the mathematical theory of fractional calculus, including ordinary and partial differential equations of fractional order, inverse problems, and evolution equations.

Basic Theory of Fractional Differential Equations
This book introduces a series of problems and methods insufficiently discussed in the field of Fractional Calculus - a major, emerging tool relevant to all areas of scientific inquiry. The authors present examples based on symbolic computation, written in Maple and Mathematica, and address both mathematical and computational areas in the context of mathematical modeling and the generalization of classical integer-order methods. Distinct from most books, the present volume fills the gap between mathematics and computer fields, and the transition from integer- to fractional-order methods.

Fractional Equations and Models
This book is a landmark title in the continuous move from integer to non-integer in mathematics: from integer numbers to real numbers, from factorials to the gamma function, from integer-order models to models of an arbitrary order. For historical reasons, the word ‘fractional’ is used instead of the word ‘arbitrary’. This book is written for readers who are new to the fields of fractional derivatives and fractional-order mathematical models, and feel that they need them for developing more adequate mathematical models. In this book, not only applied scientists, but also pure mathematicians will find fresh motivation for developing new methods and approaches in their fields of research. A reader will find in this book everything necessary for the initial study and immediate application of fractional derivatives fractional differential equations, including several necessary special functions, basic theory of fractional differentiation, uniqueness and existence theorems, analytical numerical methods of solution of fractional differential equations, and many inspiring examples of applications. A unique survey of many applications of fractional calculus Presents basic theory Includes a unified presentation of selected classical results, which are important for applications Provides many examples Contains a separate chapter of fractional order control systems, which opens new perspectives in control theory The first systematic consideration of Caputo's fractional derivative in comparison with other selected approaches Includes tables of fractional derivatives, which can be used for evaluation of all considered types of fractional derivatives

Time-Fractional Differential Equations
The Variable-Order Fractional Calculus of Variations is devoted to the study of fractional operators with variable order and, in particular, variational problems involving variable-order operators. This brief presents a new numerical tool for the solution of differential equations involving Caputo derivatives of fractional variable order. Three Caputo-type fractional operators are considered, and for each one, an approximation formula is obtained in terms of standard (integer-order) derivatives only. Estimations for the error of the approximations are also provided. The contributors consider variational problems that may be subject to one or more constraints, where the functional depends on a combined Caputo derivative of variable fractional order. In particular, they establish necessary optimality conditions of Euler-Lagrange type. As the terminal point in the cost integral is free, as is the terminal state, transversality conditions are also obtained. The Variable-Order Fractional Calculus of Variations is a valuable source of information for researchers in mathematics, physics, engineering, control and optimization; it provides both analytical and numerical methods to deal with variational problems. It is also of interest to academics and postgraduates in these fields, as it solves multiple variational problems subject to one or more constraints in a single brief.

Fractional-Order Equations and Inclusions
Fuzzy Arbitrary Order System
This book features original research articles on the topic of mathematical modelling and fractional differential equations. The contributions, written by leading researchers in the field, consist of chapters on classical and modern dynamical systems modelled by fractional differential equations in physics, engineering, signal processing, fluid mechanics, and bioengineering, manufacturing, systems engineering, and project management. The book offers theory and practical applications for the solutions of real-life problems and will be of interest to graduate level students, educators, researchers, and scientists interested in mathematical modelling and its diverse applications. Features Presents several recent developments in theory and application of fractional calculus Includes chapters on different analytical and numerical methods dedicated to several mathematical equations Develops methods for the mathematical models which are governed by fractional differential equations Provides methods for models in physics, engineering, signal processing, fluid mechanics, and bioengineering Discusses real-world problems, theory, and applications

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Fractional Differentiation

Inequalities

This graduate textbook provides a self-contained introduction to modern mathematical theory on fractional differential equations. It addresses both ordinary and partial differential equations with a focus on detailed solution theory, especially regularity theory under realistic assumptions on the problem data. The text includes an extensive bibliography, application-driven modeling, extensive exercises, and graphic illustrations throughout to complement its comprehensive presentation of the field. It is recommended for graduate students and researchers in applied and computational mathematics, particularly applied analysis, numerical analysis and inverse problems.

Lie Symmetry Analysis of Fractional Differential Equations

In the last two decades, fractional (or non integer) differentiation has played a very important role in various fields such as mathematical physics, chemistry, biology, economics, control theory and signal and image processing. For example, in the last three fields, some important considerations such as modelling, curve fitting, filtering, pattern recognition, edge detection, identification, stability, controllability, observability and robustness are now linked to long-range dependence phenomena. Similar progress has been made in other fields listed here. The scope of the book is thus to present the state of the art in the study of fractional systems and the application of fractional differentiation. As this volume covers recent applications of fractional calculus, it will be of interest to engineers, scientists, and applied mathematicians.

Fractional Calculus for Hydrology, Soil Science and Geomechanics

This is a modified version of Module 10 of the Centre for Mathematical and Statistical Sciences (CMSS). CMSS modules are notes prepared on various topics with many examples from real-life situations and exercises so that the subject matter becomes interesting to students. These modules are used for undergraduate level courses and graduate level training in various topics at CMSS. Aside from Module 8, these modules were developed by Dr A M Mathai, Director of CMSS and Emeritus Professor of Mathematics and Statistics, McGill University, Canada. Module 8 is based on the lecture notes of Professor W J Anderson of McGill University, developed for his undergraduate course (Mathematics 447). Professor Dr Hans J Haubold has been a research collaborator of Dr A M Mathai since 1984, mainly in the areas of astrophysics, special functions and statistical distribution theory. He is also a lifetime member of CMSS and a Professor at CMSS. A large number of papers have been published jointly in these areas since 1984. The following monographs and books have been brought out in conjunction with this joint research: Modern Problems in Nuclear and Neutrino Astrophysics (A M Mathai and H J Haubold, 1988, Akademie-Verlag, Berlin); Special Functions for Applied Scientists (A M Mathai and H J Haubold, 2008, Springer, New York); and The H-Function: Theory and Applications (A M Mathai, R K Saxena and H J Haubold, 2010, Springer, New York). These CMSS modules are printed at CMSS Press and published by CMSS. Copies are made available to students free of charge, and to researchers and others at production cost. For the preparation of the initial drafts of all these modules, financial assistance was made available from the Department of Science and Technology, the Government of India (DST), New Delhi under project number SR/S4/MS:287/05. Hence, the authors would like to express their thanks and gratitude to DST, the Government of India, for its financial assistance.

Introduction to Fractional Differential Equations

An Introduction to Fractional Control outlines the theory, techniques and applications of fractional control.

Theory and Applications of Fractional Differential Equations

In this book, there are five chapters: The Laplace Transform, Systems of Homogenous Linear Differential Equations (HLDE), Methods of First and Higher Orders Differential Equations, Generalized Methods of First and Higher Orders Differential Equations, and Applications of Differential Equations. In addition, there are exercises at the end of each chapter above to let students practice additional sets of problems other than examples, and they can also check their solutions to some of these exercises by looking at “Answers to Odd-Numbered Exercises” section at the end of this book. This book is a very useful for college students who studied Calculus II, and other students who want to review some concepts of differential equations before studying courses such as partial differential equations, applied mathematics, and electric circuits II.

Fractals in Biology and Medicine

This book provides a broad overview of the latest developments in fractional calculus and fractional differential equations (FDEs) with an aim to motivate the readers to venture into these areas. It also presents original research describing the fractional operators of variable order, fractional-order delay differential equations, chaos and related phenomena in detail. Selected results on the stability of solutions of nonlinear dynamical systems of the non-commensurate fractional order have also been included. Furthermore, artificial neural network and fractional differential equations are elaborated on; and new transform methods (for example, Sumudu methods) and how they can be employed to solve fractional differential equations are also discussed. Fractional transforms methods for solving FDEs, the Adomian decomposition method and its applications to fractional versions of the classical Poisson processes, variable-order fractional operators, fractional variational principles, fractional delay differential equations, fractional-order dynamical systems and stability analysis, inequalities and comparison theorems in FDEs, artificial neural network approximation for fractional operators, and new transform methods for solving partial FDEs. Given its scope and level of detail, the book will be an invaluable asset for researchers working in these areas.

Fuzzy Fractional Differential Operators and Equations

The book presents a concise introduction to the basic methods and strategies in fractional calculus which enables the reader to catch up with the state-of-the-art in this field and to participate and contribute in the development of this exciting research area. This book is devoted to the application of fractional calculus on physical problems. The fractional concept is applied to subjects in classical mechanics, image processing, folded potentials in cluster physics, infrared spectroscopy, group theory, quantum mechanics, non-Newtonian fluid mechanics, and quantum mechanics. This book will serve the researcher to intriguing insights. This book has been enriched by integrating additional chapters about numerical solution of the fractional Schrödinger equation, self-similarity and the geometric interpretation of non-isotropic fractional differential operators. Motivated by the positive response, new exercises with elaborated solutions are added, which significantly support a deeper understanding of the general aspects of the theory. Besides students as well as researchers in this field, this book will also be useful as a supporting medium for teachers teaching courses devoted to this subject.

Numerical Methods for Fractional Calculus Fractional calculus is a collection of relatively little-known mathematical results concerning generalizations of differentiation and integration to noninteger orders. While these results have been accumulated over centuries in various branches of mathematics, they have until recently found little appreciation or application in physics and other mathematically oriented sciences. This situation is beginning to change, and there are now a growing number of research areas in physics which employ fractional calculus. This book provides an introduction to fractional calculus for physicists, and collects easily accessible review articles surveying the areas of physics in which applications of fractional calculus have recently become prominent. Contents: An introduction to Fractional Calculus (P L Butzer & U Westphal) Fractional Evolutionary Processes (J W Yang & P L Butzer & U Westphal) Fractional Powers of Infinitesimal Generators of Semigroups (U Westphal) Fractional Differences, Derivatives and Fractal Time Series (B J West & P Grigolini) Fractional Kinetics of Hamiltonian Chaotic Systems (G M Zaslavsky) Polymer Science Applications of Path-Integration, Integral Equations, and Fractional Calculus (J F Douglas) Applications to Problems in Polymer Physics and Rheology (H Schiessel et al.) Applications of Fractional Calculus Techniques to Problems in Biophysics (T F Nonnenmacher & R Metzler) Fractional Calculus and Regular Variation in Thermodynamics (R Hilfer) Readership: Statistical, theoretical and mathematical physicists. Keywords: Fractional Calculus in Physics Reviews: “This monograph provides a systematic treatment of the theory and applications of fractional calculus and is an excellent starting point for both specialists and non-specialists who are interested in the subject.”

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Applications of fractional calculus for physicists. It contains nine review articles surveying those areas in which fractional calculus has become important. All the chapters are self-contained.” Mathematics Abstracts

A Friendly Introduction to Differential Equations Starting with an introduction to fractional derivatives and numerical approximations, this book presents finite difference methods for fractional differential equations, including time-fractional sub-diffusion equations, time-fractional wave equations, and space-fractional differential equations, among others. Approximation methods for fractional derivatives are developed and approximate accuracies are analyzed in detail.

Fractional Differential Equations: Numerical Methods for Applications This volume is number four in a series of proceedings volumes from the International Symposia on Fractals in Biology and Medicine in Ascona, Switzerland which have been inspired by the work of Benoît Mandelbrot seeking to extend the concepts towards the life sciences. It highlights the potential that fractal geometry offers for elucidating and explaining the complex make-up of cells, tissues and biological organisms either in normal or in pathological conditions.

Fractional Functional Calculus Fractional equations and models play an essential part in the description of anomalous dynamics in complex systems. Recent developments in the modeling of various physical, chemical and biological systems have clearly shown that fractional calculus is not just an exotic mathematical theory, as it might have once seemed. The present book seeks to demonstrate this using various examples of equations and models with fractional and generalized operators. Intended for students and researchers in mathematics, physics, chemistry, biology and engineering, it systematically offers a wealth of useful tools for fractional calculus.

Introduction to Fractional Differential Equations This book introduces a series of problems and methods insufficiently discussed in the field of Fractional Calculus – a major, emerging tool relevant to all areas of scientific inquiry. The authors present examples based on symbolic computation, written in Maple and Mathematica, and address both mathematical and computational areas in the context of mathematical modeling and the generalization of classical integer-order methods. Distinct from most books, the present volume fills the gap between mathematics and computer fields, and the transition from integer- to fractional-order methods.

Fractional Differential Equations This invaluable monograph is devoted to a rapidly developing area on the research of qualitative theory of fractional ordinary and partial differential equations. It provides the readers the necessary background material required to go further into the subject and explore the rich research literature. The tools used include many classical and modern nonlinear analysis methods such as fixed point theory, measure of noncompactness method, topological degree method, the technique of Picard operators, critical point theory and semigroup theory. Based on the research work carried out by the authors and other experts during the past seven years, the contents are very recent and comprehensive. In this edition, two new topics have been added, that is, fractional impulsive differential equations, and fractional partial differential equations including fractional Navier-Stokes equations and fractional diffusion equations. Contents: Preliminaries: Introduction Some Notations, Concepts and Lemmas Fractional Calculus Some Results from Nonlinear Analysis Semigroups Fractional Functional Differential Equations: Introduction Neutral Equations with Bounded Delay Type Neutral Equations Neutral Equations with Infinite Delay Iterative Functional Differential Equations Notes and Remarks Fractional Ordinary Differential Equations in Banach Spaces: Introduction Cauchy Problems via Measure of Noncompactness Method Cauchy Problems via Picard Operators Technique Notes and Remarks Fractional Abstract Evolution Equations: Introduction Evolution Equations with Riemann–Liouville Derivative Evolution Equations with Caputo Derivative Nonlocal Problems for Evolution Equations Abstract Cauchy Problems with Almost Sectorial Operators Notes and Remarks Fractional Differential Equations: Impulsive Boundary Value Problems Value Problems Value Problems Impulsive Evolution Equations Notes and Remarks Fractional Boundary Value Problems: Introduction Solution for BVP with Left and Right Fractional Integrals Multiple Solutions for BVP with Parameters Infinite Solutions for BVP with Left and Right Fractional Integrals Solutions for BVP with Left and Right Fractional Derivatives Notes and Remarks Fractional Partial Differential Equations: Introduction Fractional Navier–Stokes Equations Fractional Euler–Lagrange Equations Fractional Diffusion Equations Fractional Schrödinger Equations Notes and Remarks Readership: Researchers and graduate or PhD students dealing with fractional calculus and applied analysis, differential equations and related areas of research.

An Introduction to the Fractional Calculus and Fractional Differential Equations This work aims to present, in a systematic manner, results including the existence and uniqueness of solutions for the Cauchy Type and Cauchy problems involving nonlinear ordinary fractional differential equations.

Fractional Calculus In this book the author presents the Opial, Poincaré, Sobolev, Hilbert, and Ostrowski fractional differentiation inequalities. Results for the above are derived using three different types of fractional derivatives, namely by Canavati, Riemann–Liouville and Caputo. The univariate and multivariate cases are both examined. Each chapter is self-contained. The theory is presented systematically along with the applications. The application to information theory is also examined. This monograph is suitable for researchers and graduate students in pure mathematics. Applied mathematicians, engineers, and other applied scientists will also find this book useful.

Methods of Mathematical Modelling This Special Issue is devoted to some serious problems that the Fractional Calculus (FC) is currently confronted with and aims at providing some answers to the questions like “What are the fractional integrals and derivatives?”, “What are their decisive mathematical properties?”, “What fractional operators make sense in applications and why?”, etc. In particular, the “new fractional derivatives and integrals” and the models with these fractional order operators are critically addressed. The Special Issue contains papers that cover various aspects of FC and the research contributions to this part of the field, and they make the connections of FC that are considered from the viewpoints of the pure and applied mathematics, and the system theory. Another part of the Special Issue addresses the applications of the FC operators and the fractional differential equations. Several articles devoted to the numerical treatment of the FC operators and the fractional differential equations complete the Special Issue.

An Introduction to Fractional Control Topics Fractional Differential Equations is devoted to the existence and uniqueness of solutions for various classes of Darboux problems for hyperbolic differential equations or inclusions involving the Caputo fractional derivative. Fractional calculus generalizes the integrals and derivatives to non-integer orders. During the last decade, fractional calculus was found to play a fundamental role in the modeling of a considerable number of phenomena; in particular the modeling of memory-dependent and complex media such as porous media. It has emerged as an important tool for the study of dynamical systems where classical methods reveal strong limitations. Some equations present delays which may be finite, infinite, or state-dependent. Others are subject to an impulsive effect. The above problems are studied using the fixed point approach, the method of upper and lower solution, and the Kuratowski measure of noncompactness. This book is addressed to a wide audience of specialists such as mathematicians, engineers, biologists, and physicists.
Fractional Calculus and Fractional Differential Equations

Commemtates with the historical development of fractional calculus, its mathematical theory—particularly the Riemann-Liouville version. Numerous examples and theoretical applications of the theory are presented. Features topics associated with fractional differential equations. Discusses Weyl fractional calculus and some of its uses. Includes selected physical problems which lead to fractional differential or integral equations.

Fractional Differential Equations Numerical Methods for Fractional Calculus presents numerical methods for fractional integrals and fractional derivatives, finite difference methods for fractional ordinary differential equations (FODEs) and fractional partial differential equations (FPDEs), and finite element methods for FPDEs. The book introduces the basic definitions and properties.

Wavelet Methods for Solving Partial Differential Equations and Fractional Differential Equations This book is an unique integrated treatise, on the concepts of fractional calculus as models with applications in hydrology, soil science and geomechanics. The models are primarily fractional partial differential equations (FPDEs), and in limited cases, fractional differential equations (FDEs). It develops and applies relevant FDEs and FDEs to water flow and solute transport in porous media and overland, and in some cases, to concurrent flow and energy transfer. It is an integrated resource with theory and applications for those interested in hydrology, hydraulics and fluid mechanics. The self-contained book summaries the fundamentals for porous media and essential mathematics with extensive references supporting the development of the model and applications.

Implicit Fractional Differential and Integral Equations Presents a systematic treatment of fuzzy fractional differential equations as well as newly developed computational methods to model uncertain physical problems. Complete with comprehensive results and solutions, Fuzzy Arbitrary Order System: Fuzzy Fractional Differential Equations and Applications details newly developed methods of fuzzy calculus that are optimal and yield consistent results. Fuzzy differential equations are solved via various analytical and numerical methodologies, and this book presents their importance for problem solving, prototype engineering design, and systems testing in uncertain environments. In recent years, modeling of differential equations for arbitrary and fractional order systems has been increasing in its applicability, and as such, the authors feature examples from a variety of disciplines to illustrate the practicality and importance of the methods within physics, applied mathematics, engineering, and chemistry, to name a few. The fundamentals of fractional differential equations and the basic preliminaries of fuzzy fractional differential equations are first introduced, followed by numerical solutions, comparisons of various methods, and simulated results. In addition, fuzzy ordinary, partial, linear, and nonlinear fractional differential equations are addressed to solve uncertainty in physical systems. In addition, this book features: Basic preliminaries of fuzzy sets and fuzzy logic. An introduction to fractional calculus and fractional differential equations. Various analytical and numerical procedures for solving associated problems. Coverage of various types of fuzzy fractional differential equations including structural, diffusion, and chemical problems as well as heat equations and biomathematical applications. Discussions on how to model physical problems in terms of nonprobabilistic models and provides systematic coverage of fuzzy fractional differential equations and its applications Uncertainties in systems and processes with a fuzzy concept Fuzzy Arbitrary Order System: Fuzzy Fractional Differential Equations and Applications is an ideal resource for practitioners, researchers, and academicians in applied mathematics, physics, biology, engineering, computer science, and chemistry who need to model uncertain physical phenomena and problems. The book is appropriate for graduate-level courses on fractional differential equations for students majoring in applied mathematics, engineering, physics, and computer science.

Fractional Differential Equations This book provides a comprehensive set of practical tools for exploring and discovering the world of fractional calculus and its applications, and thereby a means of bridging the theory of fractional differential equations with real-world facts. These tools seamlessly blend centuries old numerical methods such as Gaussian quadrature that have stood the test of time with pioneering concepts such as hypermatrix equations to harness the emerging capabilities of modern scientific computing environments. This unique fusion of old and new leads to a unified approach that intuitively parallels the classic theory of differential equations, and results in methods that are unprecedented in computational speed and numerical accuracy. The opening chapter is an introduction to fractional calculus that is geared towards scientists and engineers. The following chapter introduces the reader to the key concepts of approximation theory with an emphasis on the tools of numerical linear algebra. The third chapter provides the keystone for the remainder of the book with a comprehensive set of practical methods for the approximation of system matrices and derivatives. The fourth chapter describes numerical systems of initial and boundary value problems for FDE of a single variable, both linear and nonlinear. Moving to two, three, and four dimensions, the ensuing chapter is devoted to a novel approach to the numerical solution of partial FDE that leverages the little-known one-to-one relation between partial differential equations and matrix and hypermatrix equations. The emphasis on applications culminates in the final chapter by addressing inverse problems for ordinary and partial FDE, such as smoothing for data analytics, and the all-important system identification problem. Over a century ago, scientists such as Ludwig Boltzmann and Vito Volterra formulated mathematical models of real materials that -- based on physical evidence -- integrated the history of the system. The present book will be invaluable to students and researchers in fields where analogous phenomena arise, such as viscoelasticity, rheology, polymer dynamics, non-Newtonian fluids, bioengineering, electrochemistry, non-conservative mechanics, groundwater hydrology, NMR and computed tomography, mathematical economics, thermomechanics, anomalous diffusion and transport, control theory, supercapacitors, and genetic algorithms, to name but a few. These investigators will be well-equipped with reproducible numerical methods to explore and discover their particular field of application of FDE.

Fractional Differential Equations General Fractional Derivatives: Theory, Methods and Applications provides knowledge of the special functions with respect to another function, and the integro-differential operators where the integrals are of the convolution type and exist the singular, weakly singular and nonsingular kernels, which exhibit the fractional derivatives, fractional integrals, general fractional derivatives, and general fractional integrals of the constant and variable order without and with respect to another function due to the appearance of the power-law and complex herbivores to figure out the modern developments in theoretical and applied science. Features: Give some new results for fractional calculus of constant and
variable orders. Discuss some new definitions for fractional calculus with respect to another function. Provide definitions for general fractional calculus of constant and variable orders. Report new results of general fractional calculus with respect to another function. Propose new special functions with respect to another function and their applications. Present new models for the anomalous relaxation and rheological behaviors. This book serves as a reference book and textbook for scientists and engineers in the fields of mathematics, physics, chemistry and engineering, senior undergraduate and graduate students. Dr. Xiao-Jun Yang is a full professor of Applied Mathematics and Mechanics, at China University of Mining and Technology, China. He is currently an editor of several scientific journals, such as Fractals, Applied Numerical Mathematics, Mathematical Modelling and Analysis, International Journal of Numerical Methods for Heat & Fluid Flow, and Thermal Science.

Fractional-Order Control Systems Fractional calculus was first developed by pure mathematicians in the middle of the 19th century. Some 100 years later, engineers and physicists have found applications for these concepts in their areas. However there has traditionally been little interaction between these two communities. In particular, typical mathematical works provide extensive findings on aspects with comparatively little significance in applications, and the engineering literature often lacks mathematical detail and precision. This book bridges the gap between the two communities by concentrating on applications, the Caputo operators, and much more general methods for solving many problems in mathematics, probability and statistics, applied computer science and numerical methods. Combining mathematical rigor with an illuminating exposition full of historical notes and practical tools, but also as vehicles that deliver theoretical insights. Presents the universal transmutation method as the most powerful for solving many problems in mathematics, probability and statistics, applied computer science and numerical methods. In addition to being exposed to recent advances, readers learn to use transmutation methods not only as theoretical insights, but also as practical tools for solving many problems in mathematics, probability and statistics, applied computer science and numerical methods. The text is a useful tool for mathematicians and researchers from the applied sciences alike. It can also be used as a basis for teaching graduate courses on fractional differential equations.

Advances in Fractional Calculus This book contains new and useful materials concerning fuzzy fractional differential and integral operators and their relationship. As the title of the book suggests, the fuzzy subject matter is one of the most important tools discussed. Therefore, it begins by providing a brief but important and new description of fuzzy sets and the computational calculus they require. Fuzzy fractals and fractional operators have a broad range of applications in the engineering, medical and economic sciences. Although these operators have been addressed briefly in previous papers, this book represents the first comprehensive collection of all relevant explanations. Most of the real problems in the biological and engineering sciences involve dynamic models, which are defined by fuzzy fractional operators in the form of fuzzy fractional initial value problems. Another important goal of this book is to solve these systems and analyze their solutions both theoretically and numerically. Given the content covered, the book will benefit all researchers and students in the mathematical and computer sciences, but also the engineering sciences.

Contents

Fractional Difference Equations Fractional Differential Equations Fractional Evolution Equations continued Fractional Differential Inclusions

Fractional Differential Equations This book deals with the existence and stability of solutions to initial and boundary value problems for fractional differential and integral equations and inclusions involving the Riemann-Liouville, Caputo, and Hadamard fractional derivatives and integrals. A wide variety of topics is covered in a mathematically rigorous manner making this work a valuable source of information for graduate students and researchers working with problems in fractional calculus. The book is of interest to mathematicians and physicists, engineers, and computer scientists.

Douglas R. Anderson: Topics in Fractional Differential Equations. This book aims to establish a foundation for fractional derivatives and fractional differential equations. The theory of fractional derivatives
enables considering any positive order of differentiation. The history of research in this field is very long, with its origins dating back to Leibniz. Since then, many great mathematicians, such as Abel, have made contributions that cover not only theoretical aspects but also physical applications of fractional calculus. The fractional partial differential equations govern phenomena depending both on spatial and time variables and require more subtle treatments. Moreover, fractional partial differential equations are highly demanded model equations for solving real-world problems such as the anomalous diffusion in heterogeneous media. The studies of fractional partial differential equations have continued to expand explosively. However, we observe that available mathematical theory for fractional partial differential equations is not still complete. In particular, operator-theoretical approaches are indispensable for some generalized categories of solutions such as weak solutions, but feasible operator-theoretic foundations for wide applications are not available in monographs. To make this monograph more readable, we are restricting it to a few fundamental types of time-fractional partial differential equations, forgoing many other important and exciting topics such as stability for nonlinear problems. However, we believe that this book works well as an introduction to mathematical research in such vast fields.

An Introduction to Fractional Calculus 
The main focus of the book is to implement wavelet based transform methods for solving problems of fractional order partial differential equations arising in modelling real physical phenomena. It explores analytical and numerical approximate solution obtained by wavelet methods for both classical and fractional order partial differential equations.

The Variable-Order Fractional Calculus of Variations 
When a new extraordinary and outstanding theory is stated, it has to face criticism and skepticism, because it is beyond the usual concept. The fractional calculus though not new, was not discussed or developed for a long time, particularly for lack of its application to real life problems. It is extraordinary because it does not deal with ‘ordinary’ differential calculus. It is outstanding because it can now be applied to situations where existing theories fail to give satisfactory results. In this book not only mathematical abstractions are discussed in a lucid manner, with physical mathematical and geometrical explanations, but also several practical applications are given particularly for system identification, description and then efficient controls. The normal physical laws like, transport theory, electrodynamics, equation of motions, elasticity, viscosity, and several others of are based on ‘ordinary’ calculus. In this book these physical laws are generalized in fractional calculus contexts; taking, heterogeneity effect in transport background, the space having traps or islands, irregular distribution of charges, non-ideal spring with mass connected to a pointless-mass ball, material behaving with viscous as well as elastic properties, system relaxation with and without memory, physics of random delay in computer network; and several others; mapping the reality of nature closely. The concept of fractional and complex order differentiation and integration are elaborated mathematically, physically and geometrically with examples. The practical utility of local fractional differentiation for enhancing the character of singularity at phase transition or characterizing the irregularity measure of response function is deliberated. Practical results of viscoelastic experiments, fractional order controls experiments, design of fractional controller and practical circuit synthesis for fractional order elements are elaborated in this book. The book also maps theory of classical integer order differential equations to fractional calculus contexts, and deals in details with conflicting and demanding initialization issues, required in classical techniques. The book presents a modern approach to solve the ‘solvable’ system of fractional and other differential equations, linear, non-linear; without perturbation or transformations, but by applying physical principle of action-and-opposite-reaction, giving ‘approximately exact’ series solutions. Historically, Sir Isaac Newton and Gottfried Wilhelm Leibniz independently discovered calculus in the middle of the 17th century. In recognition to this remarkable discovery, J.von Neumann remarked, “the calculus was the first achievement of modern mathematics and it is difficult to overestimate its importance. I think it defines more equivocally than anything else the inception of modern mathematical analysis which is logical development, still constitute the greatest technical advance in exact thinking.” This XXI century has thus started to ‘think-exactly’ for advancement in science & technology by growing application of fractional calculus, and this century has started speaking the language which nature understands the best.

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