

Basics of fractional calculus and fractional order differential equations

2

2.1 Short history of fractional calculus and fractional order differential equations

Operators of fractional integro-differentiation play an important role in many modern fields of mathematics. For special function theory its importance is reflected in the title of the well-known paper [253] “*All special functions are fractional integrals of elementary functions!*” (But there is a remark of Professor A. A. Kilbas – all but Fox functions.)

In this section we list essential one- and multi-dimensional fractional operators and include some historical and priority information.

2.1.1 One-dimensional fractional derivatives and integrals

Euler’s introduction in 1729 of the gamma function (1.1) allowed to expand the concept of factorial to the case of a fractional value of the argument. This, in turn, allowed Euler to note that the concept of the n -th order derivative of the power function x^p acquired meaning for a nonintegral n . Namely, let $n, p \in \mathbb{N}$ and $p \geq n$. It is well known that

$$(x^p)' = px^{p-1}, \quad (x^p)'' = p(p-1)x^{p-2}, \dots, \\ (x^p)^{(n)} = p(p-1)\dots(p-n+1)x^{p-n}$$

or

$$(x^p)^{(n)} = \frac{p!}{(p-n)!} x^{p-n}. \quad (2.1)$$

Expression (2.1) can also be meaningful for noninteger n and p . Namely, by virtue of the well-known equality for the gamma function

$$\Gamma(p+1) = p(p-1)\dots(p-n+1)\Gamma(p-n+1),$$

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Bangti Jin



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An Introduction to the Fractional Calculus and Fractional Differential Equations Kenneth S. Miller, Bertram Ross, 1993-06-02 Commences 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 Igor Podlubny, 1998-10-27 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 Adam Kubica, Katarzyna Ryszewska, Masahiro Yamamoto, 2020-11-29 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

Introduction to Fractional Differential Equations Constantin Milici, Gheorghe Drăgănescu, J. Tenreiro Machado, 2018-10-28 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

Introduction To The Fractional Calculus Of Variations Delfim F M Torres, Agnieszka Barbara Malinowska, 2012-09-14 This invaluable book provides a broad introduction to the fascinating and beautiful subject of Fractional Calculus of Variations FCV In 1996 FVC evolved in order to better describe non conservative systems in mechanics The inclusion of non conservatism is extremely important from the point of view of applications Forces that do not store energy are always present in real systems They remove energy from the systems and as a consequence Noether's conservation laws cease to be valid However it is still possible to obtain the validity of Noether's principle using FCV The new theory provides a more realistic approach to physics allowing us to consider non conservative systems in a natural way The authors prove the necessary Euler Lagrange conditions and corresponding Noether theorems for several types of fractional variational problems with and without constraints using Lagrangian and Hamiltonian formalisms Sufficient optimality conditions are also obtained under convexity and Leitmann's direct method is discussed within the framework of FCV The book is self contained and unified in presentation It may be used as an advanced textbook by graduate students and ambitious undergraduates in mathematics and mechanics It provides an opportunity for an introduction to FCV for experienced researchers The explanations in the book are detailed in order to capture the interest of the curious reader and the book provides the necessary background material required to go further into the subject and explore the rich research literature a

Fractional Calculus and Fractional Differential Equations Varsha Daftardar-Gejji, 2019-08-10 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 partial differential equations are discussed The

book covers the latest research on a variety of topics including comparison of various numerical 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 Fractional Calculus Varsha Daftardar-Gejji, 2013-07-26

FRACTIONAL CALCULUS Theory and Applications deals with differentiation and integration of arbitrary order The origin of this subject can be traced back to the end of seventeenth century the time when Newton and Leibniz developed foundations of differential and integral calculus Nonetheless utility and applicability of FC to various branches of science and engineering have been realized only in last few decades Recent years have witnessed tremendous upsurge in research activities related to the applications of FC in modeling of real world systems Unlike the derivatives of integral order the non local nature of fractional derivatives correctly models many natural phenomena containing long memory and give more accurate description than their integer counterparts The present book comprises of contributions from academicians and leading researchers and gives a panoramic overview of various aspects of this subject Introduction to Fractional Calculus Fractional Differential Equations Fractional Ordered Dynamical Systems Fractional Operators on Fractals Local Fractional Derivatives Fractional Control Systems Fractional Operators and Statistical Distributions Applications to Engineering An Introduction to Fractional Differential Equations K. Balachandran, 2023-11-23 This is an introductory level text on fractional calculus and fractional differential equations Targeted to graduate students of mathematics and researchers it contains several new definitions of fractional integrals and fractional derivatives With interesting applications of the subject in several areas of physical sciences life sciences engineering and technology the book helps the students understand the importance and developments of this topic The book is enriched with a list of useful references to published literature and the presentation of the book is entirely new and easily comprehensible to the students Some of the topics are refined and new examples are included to supplement theories to help students understand the concepts easily and clearly **Fractional Differential Equations** Bangti Jin, 2021-07-22 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 **Fractional Calculus with its Applications in Engineering and Technology** Yi Yang, Haiyan Henry Zhang, 2019-03-28 This book aims to provide

the basic theory of fractional calculus and its applications based on practical schemes and approaches illustrated with applicable engineering and technical examples especially focusing on the fractional order controller design In the development of this book the essential theorems and facts in the first two chapters are proven with rigorous mathematical analyses In addition the commonly used definitions of Gr nwald Letnikov Riemann Liouville Caputo and Miller Ross fractional derivatives are introduced with their properties proved and linked to fractional order controller design The last chapter presents several enlightening scenarios of fractional order control designs for example the suppression of machining chatter the nonlinear motion control of a multilink robot the simultaneous tracking and stabilization control of a rotary inverted pendulum and the idle speed control of an internal combustion engine ICE

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Table of Contents An Introduction To The Fractional Calculus And Fractional Differential Equations

1. Understanding the eBook An Introduction To The Fractional Calculus And Fractional Differential Equations
 - The Rise of Digital Reading An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Advantages of eBooks Over Traditional Books
2. Identifying An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an An Introduction To The Fractional Calculus And Fractional Differential Equations
 - User-Friendly Interface
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 - An Introduction To The Fractional Calculus And Fractional Differential Equations User Reviews and Ratings

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 - An Introduction To The Fractional Calculus And Fractional Differential Equations Budget-Friendly Options
- 6. Navigating An Introduction To The Fractional Calculus And Fractional Differential Equations eBook Formats
 - ePub, PDF, MOBI, and More
 - An Introduction To The Fractional Calculus And Fractional Differential Equations Compatibility with Devices
 - An Introduction To The Fractional Calculus And Fractional Differential Equations Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Highlighting and Note-Taking An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Interactive Elements An Introduction To The Fractional Calculus And Fractional Differential Equations
- 8. Staying Engaged with An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers An Introduction To The Fractional Calculus And Fractional Differential Equations
- 9. Balancing eBooks and Physical Books An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection An Introduction To The Fractional Calculus And Fractional Differential Equations
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Setting Reading Goals An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Fact-Checking eBook Content of An Introduction To The Fractional Calculus And Fractional Differential Equations
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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