



Fractional calculus with an integral operator containing a generalized Mittag–Leffler function in the kernel

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ABSTRACT

In this paper, we introduce and investigate a fractional calculus with an integral operator which contain the following family of generalized Mittag–Leffler function:

$$E_{\alpha,\beta,\gamma}^{\delta}(x) = \sum_{n=0}^{\infty} \frac{(\gamma)_n}{\Gamma(\alpha n + \beta)} \frac{x^n}{n!} \quad (\alpha, \beta, \gamma \in \mathbb{C}; \Re(x) > \max(0, \Re(\alpha) - 1), \Re(x) > 0)$$

in its kernel, $(\gamma)_n$ being the familiar Pochhammer symbol. A number of corollaries and consequences of the main results presented here are also considered.

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1. Introduction, definitions and preliminaries

As mentioned in the survey article by Gorenflo and Mainardi [4], even the classical Mittag–Leffler functions have remained, for a long time, almost totally ignored in the common handbooks on special functions and tables of integral transforms, although a reasonably adequate description of many of their interesting and potentially useful properties appeared already in the third volume of the celebrated Bateman Manuscript Project (see Erdélyi et al. [2, Chapter 18]) in a chapter devoted to Miscellaneous Functions). The Mittag–Leffler functions $E_{\alpha}(x)$ and $E_{\alpha,\beta}(x)$ are defined by the following series:

$$E_{\alpha}(x) = \sum_{n=0}^{\infty} \frac{x^n}{\Gamma(\alpha n + 1)} \quad (\alpha \in \mathbb{C}; \Re(\alpha) > 0) \quad (1.1)$$

and

$$E_{\alpha,\beta}(x) = \sum_{n=0}^{\infty} \frac{x^n}{\Gamma(\alpha n + \beta)} \quad (\alpha, \beta \in \mathbb{C}; \Re(\alpha) > 0), \quad (1.2)$$

respectively. These functions are natural extensions of the exponential, hyperbolic and trigonometric functions, since

$$E_1(x) = e^x, \quad E_2(x^2) = \cosh x \quad \text{and} \quad E_2(-x^2) = \cos x.$$

For a detailed account of the various properties, generalizations and applications of the Mittag–Leffler functions, the reader may refer to the recent works by (for example) Džurđević [1], Kilbas and Saigo [11], Gorenflo and Mainardi [4], Gorenflo et al.

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Fractional Calculus With An Integral Operator Containing A:

Fractional Calculus and its Applications in Physics Dumitru Baleanu, Devendra Kumar, 2019-11-15 *Fractional Differential Equations, Inclusions and Inequalities with Applications* Sotiris K. Ntouyas, 2020-11-09 During the last decade there has been an increased interest in fractional differential equations inclusions and inequalities as they play a fundamental role in the modeling of numerous phenomena in particular in physics biomathematics blood flow phenomena ecology environmental issues viscoelasticity aerodynamics electrodynamics of complex medium electrical circuits electron analytical chemistry control theory etc This book presents collective works published in the recent Special Issue SI entitled Fractional Differential Equation Inclusions and Inequalities with Applications of the journal Mathematics This Special Issue presents recent developments in the theory of fractional differential equations and inequalities Topics include but are not limited to the existence and uniqueness results for boundary value problems for different types of fractional differential equations a variety of fractional inequalities impulsive fractional differential equations and applications in sciences and engineering *Generalized Fractional Calculus and Applications* Virginia S Kiryakova, 1993-12-27 In this volume various applications are discussed in particular to the hyper Bessel differential operators and equations Dzrbashjan Gelfond Leontiev operators and Borel type transforms convolutions new representations of hypergeometric functions solutions to classes of differential and integral equations transmutation method and generalized integral transforms Some open problems are also posed This book is intended for graduate and post graduate students lecturers researchers and others working in applied mathematical analysis mathematical physics and related disciplines Fractional Calculus for Hydrology, Soil Science and Geomechanics Ninghu Su, 2020-11-02 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 fPDEs and fDEs mainly 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 *Fractional Integrals and Derivatives: "True" versus "False"* Yuri Luchko, 2021-03-16 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 both the surveys and the research contributions A part of the articles deals with foundations 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.

Special Functions in Fractional Calculus and Engineering Harendra Singh, H M Srivastava, R. K. Pandey, 2023-06-29. Special functions play a very important role in solving various families of ordinary and partial differential equations as well as their fractional order analogs which model real life situations. Owing to the non local nature and memory effect, fractional calculus is capable of modeling many situations which arise in engineering. This book includes a collection of related topics associated with such equations and their relevance and significance in engineering. *Special Functions in Fractional Calculus and Engineering* highlights the significance and applicability of special functions in solving fractional order differential equations with engineering applications. This book focuses on the non local nature and memory effect of fractional calculus in modeling relevant to engineering science and covers a variety of important and useful methods using special functions for solving various types of fractional order models relevant to engineering science. This book goes on to illustrate the applicability and usefulness of special functions by justifying their numerous and widespread occurrences in the solution of fractional order differential, integral and integrodifferential equations. This book holds a wide variety of interconnected fundamental and advanced topics with interdisciplinary applications that combine applied mathematics and engineering sciences which are useful to graduate students, Ph D scholars, researchers and educators interested in special functions, fractional calculus, mathematical modeling and engineering.

[General Fractional Derivatives with Applications in Viscoelasticity](#) Xiao-Jun Yang, Feng Gao, Yang Ju, 2020-04-03. *General Fractional Derivatives with Applications in Viscoelasticity* introduces the newly established fractional order calculus operators involving singular and non singular kernels with applications to fractional order viscoelastic models from the calculus operator viewpoint. Fractional calculus and its applications have gained considerable popularity and importance because of their applicability to many seemingly diverse and widespread fields in science and engineering. Many operations in physics and engineering can be defined accurately by using fractional derivatives to model complex phenomena. Viscoelasticity is chief among them as the general fractional calculus approach to viscoelasticity has evolved as an empirical method of describing the properties of viscoelastic materials. *General Fractional Derivatives with Applications in Viscoelasticity* makes a concise presentation of general fractional calculus. Presents a comprehensive overview of the fractional derivatives and their applications in viscoelasticity. Provides help in handling the power law functions. Introduces and explores the questions about general fractional derivatives and its applications.

Fractional Dynamics Carlo Cattani, Hari M. Srivastava, Xiao-Jun Yang, 2015-01-01. The book is devoted to recent developments in the theory of fractional calculus and its applications. Particular attention is paid to the applicability of this currently popular research field in various branches of pure and applied mathematics. In particular, the book focuses on the more recent results in mathematical physics, engineering applications, theoretical and applied physics, as quantum

mechanics signal analysis and in those relevant research fields where nonlinear dynamics occurs and several tools of nonlinear analysis are required Dynamical processes and dynamical systems of fractional order attract researchers from many areas of sciences and technologies ranging from mathematics and physics to computer science Integral Transforms and Operational Calculus H. M. Srivastava, 2019-11-20 Researches and investigations involving the theory and applications of integral transforms and operational calculus are remarkably wide spread in many diverse areas of the mathematical physical chemical engineering and statistical sciences This Special Issue contains a total of 36 carefully selected and peer reviewed articles which are authored by established researchers from many countries Included in this Special Issue are review expository and original research articles dealing with the recent advances on the topics of integral transforms and operational calculus as well as their multidisciplinary applications **Applications of Fractional Calculus to Modeling in Dynamics and Chaos** J. F. Gómez-Aguilar, Abdon Atangana, 2022-09-29 Applications of Fractional Calculus to Modeling in Dynamics and Chaos aims to present novel developments trends and applications of fractional order derivatives with power law and Mittag Leffler kernel in the areas of chemistry mechanics chaos epidemiology fluid mechanics modeling and engineering Non singular and non local fractional order derivatives have been applied in different chapters to describe complex problems 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 modeling and its diverse applications Features Discusses real world problems theory and applications Covers new developments and advances in the various areas of nonlinear dynamics signal processing and chaos Suitable to teach master s and or PhD level graduate students and can be used by researchers from any field of the social health and physical sciences Unification of Fractional Calculi with Applications George A. Anastassiou, 2021-11-21 This book demonstrates the unifying methods of generalized versions of Hilfer Prabhakar and Hilfer Prabhakar fractional calculi and we establish related unifying fractional integral inequalities of the following types Iyengar Landau Polya Ostrowski Hilbert Pachpatte Hardy Opial Csiszar s f Divergence self adjoint operator and related to fuzziness Our results are univariate and multivariate This book s results are expected to find applications in many areas of pure and applied mathematics especially in fractional inequalities and fractional differential equations Other interesting applications can be in applied sciences like geophysics physics chemistry economics and engineering This book is appropriate for researchers graduate students practitioners and seminars of the above disciplines also to be in all science and engineering libraries **Basic Theory** Anatoly Kochubei, Yuri Luchko, 2019-02-19 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 first volume collects authoritative chapters covering the mathematical theory of fractional calculus including fractional order operators integral transforms and equations special functions calculus of variations and probabilistic and other aspects **Fractional Differential Equations** Praveen Agarwal, Carlo

Cattani,Shaher Momani,2024-04-29 Fractional Differential Equations Theoretical Aspects and Applications presents the latest mathematical and conceptual developments in the field of Fractional Calculus and explores the scope of applications in research science and computational modelling Fractional derivatives arise as a generalization of integer order derivatives and have a long history their origin can be found in the work of G W Leibniz and L Euler Shortly after being introduced the new theory turned out to be very attractive for many famous mathematicians and scientists including P S Laplace B Riemann J Liouville N H Abel and J B J Fourier due to the numerous possibilities it offered for applications Fractional Calculus the field of mathematics dealing with operators of differentiation and integration of arbitrary real or even complex order extends many of the modelling capabilities of conventional calculus and integer order differential equations and finds its application in various scientific areas such as physics mechanics engineering economics finance biology and chemistry among others However many aspects from the theoretical and practical point of view have still to be developed in relation with models based on fractional operators Efficient analytical and numerical methods have been developed but still need particular attention Fractional Differential Equations Theoretical Aspects and Applications delves into these methods and applied computational modelling techniques including analysis of equations involving fractional derivatives fractional derivatives and the wave equation analysis of FDE on groups direct and inverse problems functional inequalities and computational methods for FDEs in physics and engineering Other modelling techniques and applications explored by the authors include general fractional derivatives involving the special functions in analysis fractional derivatives with respect to another function in analysis new fractional operators in real world applications fractional order dynamical systems hidden attractors in complex systems nonlinear dynamics and chaos in engineering applications quantum chaos and self excited attractors Provides the most recent and up to date developments in the theory and scientific applications Fractional Differential Equations Includes transportable computer source codes for readers in MATLAB with code descriptions as it relates to the mathematical modelling and applications Provides readers with a comprehensive foundational reference for this key topic in computational modeling which is a mathematical underpinning for most areas of scientific and engineering research Approximation Theory and Analytic Inequalities Themistocles M. Rassias,2021-07-21 This contributed volume focuses on various important areas of mathematics in which approximation methods play an essential role It features cutting edge research on a wide spectrum of analytic inequalities with emphasis on differential and integral inequalities in the spirit of functional analysis operator theory nonlinear analysis variational calculus featuring a plethora of applications making this work a valuable resource The reader will be exposed to convexity theory polynomial inequalities extremal problems prediction theory fixed point theory for operators PDEs fractional integral inequalities multidimensional numerical integration Gauss Jacobi and Hermite Hadamard type inequalities Hilbert type inequalities and Ulam s stability of functional equations Contributions have been written by eminent researchers providing up to date information and several results which may be useful to a wide

readership including graduate students and researchers working in mathematics physics economics operational research and their interconnections

General Fractional Derivatives Xiao-Jun Yang,2019-05-10 *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 news 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*

Mathematical Methods in Medical and Biological Sciences Harendra Singh,Hari M Srivastava,2024-11-05 *Mathematical Methods in Medical and Biological Sciences* presents mathematical methods for computational models arising in the medical and biological sciences The book presents several real life medical and biological models such as infectious and non infectious diseases that can be modeled mathematically to accomplish profound research in virtual environments when the cost of laboratory expenses is relatively high It focuses on mathematical techniques that provide global solutions for models arising in medical and biological sciences by considering their long term benefits In addition the book provides leading edge developments and insights for a range of applications including epidemiological modeling of pandemic dynamics viral infection developments cancer developments blood oxygen dynamics HIV infection spread reaction diffusion models polio infection spread and chaos modeling with fractional order derivatives Presents the mathematical treatment of a wide range of real life medical and biological models including both infectious and non infectious diseases Provides in depth analysis of the spread of Covid 19 polio and HIV including discussion of computational methods and applications Includes computational modeling methods along with their practical applications providing the basis for further exploration and research in epidemiology and applied biomedical sciences

Recent Developments in Algebra and Analysis Ho-Hon Leung,R. Sivaraj,Firuz Kamalov,2024-02-22 This volume collects the proceedings of the International Conference on Recent Developments in Mathematics ICRDM held at Canadian University

Dubai UAE in August 2022 It is the first of two volumes this first volume focuses on recent advances in algebra and analysis and the second volume covers more applied topics Each chapter identifies existing challenges in these theoretical areas and highlights the importance of establishing new theorems and algorithms to address them Recent Developments in Algebra and Analysis will appeal to a range of postgraduate students and researchers who are interested in exploring more on these areas and play an integral role in modern science

Frontiers in Physics - 2017 & 2018 Editor's Choice Thomas Beyer,Ewald Moser,Dieter W. Heermann,Christian F. Klingenberg,James Sauls,José W. F. Valle,Jan de Boer,Emilio Elizalde,Dumitru Baleanu,Alex Hansen,Nicholas X. Fang,Lorenzo Pavesi,Bretislav Friedrich,Christine Charles,Matjaž Perc,Jasper Van Der Gucht,Rudolf von Steiger,Claudio Bogazzi,2019-02-22 Launched in 2013 Frontiers in Physics consists of 18 specialties covering all areas of research in physics With over 500 published manuscripts the journal is now indexed in SCIE with the first impact factor coming in 2019 Frontiers in Physics aims to become the largest and most cited open access multidisciplinary physics journal This eBook collects what the Specialty Chief Editors of the journal believed were the most interesting manuscripts published over the past two years It is a nice collection which will offer the reader the chance to have a quick overview of the specialties of the journal and offer a glimpse into the state of the art of physics We must confess that it has been quite challenging to select only one article per specialty section given the many important manuscripts published by the journal in 2017 and 2018 We invite our reader to have a look at the journal homepage and browse what we have published so far It includes articles on topics very different from each other written by both early career scientists and well known researchers ranging from the indisputable advance of the field to the more bold We hope you enjoy reading our first edition of the Frontiers in Physics Editor s Choice eBook Professor Alex Hansen Field Chief Editor and Dr Claudio Bogazzi Journal Manager

Advances in Mathematical Modelling, Applied Analysis and Computation Jagdev Singh,George A. Anastassiou,Dumitru Baleanu,Carlo Cattani,Devendra Kumar,2022-10-13 This book is a valuable source for graduate students and researchers and provides a comprehensive introduction to recent theories and applications of mathematical modeling and numerical simulation It includes selected peer reviewed papers presented at the 4th International Conference on Mathematical Modelling Applied Analysis and Computation ICMMAAC 2021 held at JECRC University Jaipur India during August 5 7 2021 The book is focused on mathematical modeling of various problems arising in science and engineering and new efficient numerical approaches for solving linear nonlinear problems and rigorous mathematical theories which can be used to analyze different kinds of mathematical models Applications of mathematical methods in physics chemistry biology mechanical engineering civil engineering computer science social science and finance are presented

Mathematical and Computational Intelligence to Socio-scientific Analytics and Applications Pankaj Srivastava,M. Lellis Thivagar,Georgia Irina Oros,Chai Ching Tan,2023-01-02 This book presents a collection of selected papers presented at the 22nd FAI International Conference on Mathematical Computational Intelligence and Engineering Approaches to Healthcare Business and Tourism

Analytics FAI ICMCIE 2020 held at American College Madurai India from 20-22 December 2020. This book discusses advanced mathematical concepts and computational intelligence approaches for medical diagnostic approach in cardiac diseases, nano topology in medical diseases, stability of indicators in assessing business development, AI guided paradigmatic competence in science and spirituality integration, neural network TOPSIS analytics in hotel service quality, itinerary planning, destination ranking, tourism analytics, molecular modeling and docking simulation for unraveling medicinal properties, value oriented approach on commercial banks security, Brownian motion in shares of the bank, internet of things linking to social media and e-commerce and more which are discussed by using fuzzy analytics, nano topology, statistical TOPSIS and neural network tools.

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