fractal and fractional

MDPI

Editorial

Fractal and Fractional Analysis in Biomedical Sciences and Engineering

Andjelija Ž. Ilić

Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade-Zemun, Serbia; andjelijailic@ieee.org

The visual appearance of fractal patterns in biology has been noted from the early days of research in this field and, henceforth, has been studied for a long time. The typical examples that first come to mind include the branching of the airways in the lungs, the vasculature in the liver, and the shape of cauliflower and broccoli. Then, there are signals —heart signals, brain signals, measured gait patterns, and DNA sequences. The more the research in fractal and fractional phenomena progresses, the more the pronounced fractal behavior of biological systems at every level of organization is noticed. This Special Issue illustrates the breadth of problems, which are being investigated today using the mathematical apparatus of fractal and fractional calculus, by presenting ten papers on very diverse topics in bioscience.

Contribution No. 1 employs fractional calculus in a study of honeybee population dynamics, which is becoming a problem of increasing importance, with honeybee losses being reported in many countries nowadays. The disruption of pollination causes serious additional problems in economics, agriculture, and ecology.

Contribution No. 2 explores the potential of the fractal analysis of intestinal cell nuclei, to serve as an observer-independent histological tool for pediatric ulcerative colitis diagnosis. The investigation was motivated by the noted unfolding of chromatin in the cell nuclei in some diseases, being reflected macroscopically in the altered textures of the nuclei.

A novel unsupervised deep learning approach for characterizing the degree of fractality of dried drop patterns of plant-based homeopathic remedies is proposed in Contribution No. 3. The self- assembled structures formed in evaporating droplets differed for the three mixing procedures that were applied (turbulent, laminar, and diffusion-based mixing).

The corneal geometry of the human eye is studied in Contribution No. 4. The non-integer behavior of the corneal-shaped model is studied using several machine learning models, with the best results achieved through the use of artificial neural network based on the hybrid biogeography-based heterogeneous cuckoo search optimization technique.

The Contribution No. 5 proposes the use of a novel orthogonal matrix decomposition method in combination with the orthogonal generalized Laguerre moments of fractional orders for the analysis of large bio-signals. Due to the highly accurate and stable calculations of higher-order moments, the analysis tested on the arrhythmia dataset is very efficient.

The fractal analysis of immunohistochemical images of invasive cutaneous squamous cell carcinoma is proposed in Contribution No. 6 as the method to potentially inform the development of new diagnostic and therapeutic strategies targeting the tumor microenvironment. Quantitative analysis of the spatial distribution patterns of immune and vascular markers is used for the classification of pre-invasive and invasive lesions.

In Contribution No. 7, fractional electrodamage induced by the electrical stimulation of A549 human lung cancer cells is investigated. Experimentally obtained data is fitted and

check for updates

Received: 16 June 2025
Accepted: 11 July 2025
Published: 21 July 2025

Citation: Ilić, A.Ž. Fractal and Fractional Analysis in Biomedical Sciences and Engineering. *Fractal Fract.* **2025**, *9*, 474. https://doi.org/10.3390/fractalfract9070474

Copyright: © 2025 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

the order of the fractional derivative is selected to provide the best model of cell elongation during the electrochemical changes. Significant electrocapacitive effects were exhibited by the cells.

The scale-free dynamics of the resting state fMRI is considered in Contributiom No. 8 as a possible multimodal biomarker to study both spatial (brain tissue type and functional networks) and temporal (activation and cognition) brain dynamics. The microstate segmentation method served to obtain topological maps, and the EEG and fMRI data were used simultaneously.

The simulation-based investigation of the tumor growth and chemical diffusion in biological tissues is described in Contribution No. 9, contributing to a deeper understanding of the chemical diffusion mechanisms within tissues and tumor growth under different conditions. Fractional stochastic calculus was used to model these processes.

Finally, in Contribution No. 10, the fractional Fourier transform is combined with the error back-propagation neural network, with an aim of performing advanced image feature extraction and model generalization in tumor diagnostics. The main focus of the prediction model was distinguishing between the benign and malignant cases.

In conclusion, most of the presented articles rely on empirical, real-world data and advanced non-integer models to achieve good agreement between experimental observations and the models aiming to provide deeper insights into the studied phenomena. Numerical models, developed and trained on real-world data, can be valuable tools for the prediction of process progression and, in some cases, treatment monitoring in biomedical sciences. All of the selected papers have the potential to contribute to addressing practical problems. The proposed new methods can be applied in future to diverse sets of problems.

Funding: This research received no external funding.

Acknowledgments: The author acknowledges the funding provided by the Institute of Physics Belgrade, University of Belgrade, through the grants from the Ministry of Science, Technological Development, and Innovations of the Republic of Serbia.

Conflicts of Interest: The author declares no conflicts of interest.

List of Contributions

1. Georgiev, S.; Vulkov, L. Parameters Identification and Numerical Simulation for a Fractional Model of Honeybee Population Dynamics. *Fractal Fract.* **2023**, *7*, 311. https://doi.org/10.3390/fractalfract7040311.
2. Makević, V.; Milovanovich, I.D.; Popovac, N.; Janković, R.; Trajković, J.; Vuković, A.; Milosević, B.; Jevtić, J.; de Luka, S.R.; Ilić, A.Ž. Fractal Parameters as Independent Biomarkers in the Early Diagnosis of Pediatric Onset Inflammatory Bowel Disease. *Fractal Fract.* **2023**, *7*, 619. https://doi.org/10.3390/fractalfract7080619.
3. Acuña, C.; Kokornaczyk, M.O.; Baumgartner, S.; Castelán, M. Unsupervised Deep Learning Approach for Characterizing Fractality in Dried Drop Patterns of Differently Mixed *Viscum album* Preparations. *Fractal Fract.* **2023**, *7*, 733. https://doi.org/10.3390/fractalfract7100733.
4. Waseem; Ullah, A.; Awwad, F.A.; Ismail, E.A.A. Analysis of the Corneal Geometry of the Human Eye with an Artificial Neural Network. *Fractal Fract.* **2023**, *7*, 764. https://doi.org/10.3390/fractalfract7100764.
5. Aldakheel, E.A.; Khafaga, D.S.; Fathi, I.S.; Hosny, K.M.; Hassan, G. Efficient Analysis of Large-Size Bio-Signals Based on Orthogonal Generalized Laguerre Moments of Fractional Orders and Schwarz–Rutishauser Algorithm. *Fractal Fract.* **2023**, *7*, 826. https://doi.org/10.3390/fractalfract7110826.
6. Buruiană, A.; Șerbănescu, M.-S.; Pop, B.; Gheban, B.-A.; Gheban-Roșca, I.-A.; Hendea, R.M.; Georgiu, C.; Crișan, D.; Crișan, M. Fractal Dimension Analysis of the Tumor Microenvironment in Cutaneous Squamous Cell Carcinoma: Insights into Angiogenesis and Immune Cell Infiltration. *Fractal Fract.* **2024**, *8*, 600. https://doi.org/10.3390/fractalfract8100600.

7. Martines-Arano, H.; Arano-Martinez, J.A.; Mosso-Pani, M.A.; Valdivia-Flores, A.; Trejo-Valdez, M.; García-Pérez, B.E.; Torres-Torres, C. Fractional Electrodamage in A549 Human Lung Cancer Cells. *Fractal Fract.* **2025**, *9*, 34. https://doi.org/10.3390/fractalfract9010034.
8. Erbil, N.; Deshpande, G. Scale-Free Dynamics of Resting-State fMRI Microstates. *Fractal Fract.* **2025**, *9*, 112. https://doi.org/10.3390/fractalfract9020112.
9. Ghezal, A.; Attia, N. ϑ-Fractional Stochastic Models for Simulating Tumor Growth and Chemical Diffusion in Biological Tissues. *Fractal Fract.* **2025**, *9*, 258. https://doi.org/10.3390/fractalfract9040258.
10. Liu, X.; Gao, N.; He, S.; Wang, L. Application of Fractional Fourier Transform and BP Neural Network in Prediction of Tumor Benignity and Malignancy. *Fractal Fract.* **2025**, *9*, 267. https://doi.org/10.3390/fractalfract9050267.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.