

## POSITIVE SOLUTIONS FOR A RIEMANN–LIOUVILLE FRACTIONAL SYSTEM WITH $\rho$ –LAPLACIAN OPERATORS

WANXIN ZHANG AND CHENGBO ZHAI\*

*Abstract.* This paper studies the existence and uniqueness of positive solutions for Riemann–Liouville fractional differential equations with  $\rho$ –Laplacian operators and coupled nonlocal boundary conditions involving the Riemann–Stieltjes integrals. By means of an interesting fixed point theorem, some new sufficient conditions guaranteeing the existence and uniqueness of positive solutions are presented, and the unique positive solution can be the limit of a sequence constructed for any given initial point in a special set. To demonstrate the conclusion, a good example is given.

*Mathematics subject classification (2020):* 26A33, 34B18, 34B15.

*Keywords and phrases:* Riemann–Liouville fractional differential equations, nonlocal coupled boundary conditions, existence and uniqueness.

### REFERENCES

- [1] B. AHMAD, R. LUCA, *Existence of solutions for sequential fractional integro-differential equations and inclusions with nonlocal boundary conditions*, Appl. Math. Comput. **339** (2018) 516–534.
- [2] B. AHMAD, S. K. NTOUYAS, *A fully Hadamard type integral boundary value problem of a coupled system of fractional differential equations*, Fract. Calc. Appl. Anal. **17** (2) (2014) 348–360.
- [3] B. AHMAD, S. K. NTOUYAS, A. ALSAEDI, *A study of a coupled system of Hadamard fractional differential equations with nonlocal coupled initial-multipoint conditions*, Adv. Differ. Equ. **2021**, **33** (2021).
- [4] Z. BAITICHE, C. DERBAZI, G. WANG, *Monotone iterative method for nonlinear fractional- $\rho$ -Laplacian differential equation in terms of  $\psi$ -Caputo fractional derivative equipped with a new class of nonlinear boundary conditions*, Math. Meth. Appl. Sci. **45** (2022) 967–976.
- [5] L. CHEN, J. MA, *Solve Riemann–Liouville boundary value problems using collocation boundary value methods with the graded mesh*, J. Comput. Appl. Math. **443** (2024) 115762.
- [6] F. HADDOUCHI, M. E. SAMEL, *Solvability of a  $\psi$ -Riemann–Liouville fractional boundary value problem with nonlocal boundary conditions*, Math. Comput. Simul. **219** (2024) 355–377.
- [7] Z. HAN, H. LU, S. SUN, *Positive solutions to boundary-value problems of  $p$ -Laplacian fractional differential equations with a parameter in the boundary*, Electron. J. Differ. Equ. **213** (2012) 2012.
- [8] Z. HAN, H. LU, C. ZHANG, *Positive solutions for eigenvalue problems of fractional differential equation with generalized  $p$ -Laplacian*, Appl. Math. Comput. **257** (2015) 526–536.
- [9] J. HENDERSON, R. LUCA, *Nonexistence of positive solutions for a system of coupled fractional boundary value problems*, Bound. Value Probl. **2015**, **138** (2015).
- [10] J. HENDERSON, R. LUCA, A. TUDORACHE, *On a System of Riemann–Liouville Fractional Boundary Value Problems with  $\rho$ -Laplacian Operators and Positive Parameters*, Fractal Fract. **6** (6) (2022) 299.
- [11] J. HENDERSON, R. LUCA, A. TUDORACHE, *Positive solutions for systems of coupled fractional boundary value problems*, Open J. Appl. Sci. **5** (10) (2015) 600–608.
- [12] T. JESSADA, S. K. NTOUYAS, S. ASAWASAMRIT, *Positive solutions for Hadamard differential systems with fractional integral conditions on an unbounded domain*, Open Math. **15** (1) (2017) 645–666.
- [13] M. LI, J. WANG, *Exploring delayed Mittag–Leffler type matrix functions to study finite time stability of fractional delay differential equations*, Appl. Math. Comput. **324** (2018) 254–265.

- [14] S. LI, X. ZHANG, Y. WU, *Extremal solutions for  $p$ -Laplacian differential systems via iterative computation*, Appl. Math. Lett. **26** (12) (2013) 1151–1158.
- [15] R. LUCA, *On a system of fractional differential equations with  $p$ -Laplacian operators and integral boundary conditions*, Revue. Roum. Math. Pures. Appl. **66** (2021) 749–766.
- [16] D. LUO, T. ABDELJAWAD, Z. LUO, *Ulam-Hyers stability results for a novel nonlinear nabla Caputo fractional variable-order difference system*, Turk. J. Math. **45** (2021) 456–470.
- [17] D. LUO, Q. ZHU, Z. LUO, *A novel result on averaging principle of stochastic Hilfer-type fractional system involving non-Lipschitz coefficients*, Appl. Math. Lett. **122** (2021), 107549.
- [18] I. PODLUBNY, *Fractional Differential Equations, an Introduction to Fractional Derivatives*, Elsevier: Amsterdam, The Netherlands, 1998.
- [19] L. REN, J. WANG, M. FECKAN, *Asymptotically periodic solutions for Caputo type fractional evolution equations*, Frac. Calc. Appl. Anal. **21** (2018) 1294–1312.
- [20] C. SHEN, H. ZHOU, L. YANG, *On the existence of solution to a boundary value problem of fractional differential equation on the infinite interval*, Bound. Value Probl. 2015, **241** (2015).
- [21] A. TUDORACHE, R. LUCA, *Positive solutions for a system of fractional boundary value problems with  $r$ -Laplacian operators, uncoupled nonlocal conditions and positive parameters*, Axioms **11** (4) (2022) 164.
- [22] A. TUDORACHE, R. LUCA, *Positive solutions for a system of Riemann-Liouville fractional boundary value problems with  $p$ -Laplacian operators*, Adv. Differ. Equ. 2020, **292** (2020).
- [23] G. WANG, J. QIN, L. ZHANG, D. BALEANU, *Monotone iterative method for nonlinear fractional conformable  $p$ -Laplacian differential system*, Math. Meth. Appl. Sci. 2020, 1–11.
- [24] G. WANG, H. YUAN, D. BALEANU, *Stability analysis and solutions of fractional boundary value problem on the cyclopentasilane graph*, Heliyon **10** (2024) 32411.
- [25] J. WANG, M. FECKAN, Y. ZHOU, *Center stable manifold for planar fractional damped equations*, Appl. Math. Comput. **296** (2017) 257–269.
- [26] J. WANG, X. LI, *A uniformed method to Ulam-Hyers stability for some linear fractional equations*, Mediterr. J. Math. **13** (2016) 625–635.
- [27] J. XU, J. JIANG, D. O’REGAN, *Positive solutions for a class of  $p$ -Laplacian Hadamard fractional-order three-point boundary value problems*, Mathematics **308** (2020) 2020.
- [28] J. XU, L. LIU, S. BAI, Y. WU, *Solvability for a system of Hadamard fractional multi-point boundary value problems*, Nonlinear Anal. Model. **26** (3) (2021) 502–521.
- [29] C. YANG, H. LI, *Existence of positive solutions for a system of nonlinear Caputo type fractional differential equations with two parameters*, Adv. Differ. Equ. 2021, **497** (2021).
- [30] C. YANG, X. ZHU, *Positive solutions depending on parameters for a nonlinear fractional system with-Laplacian operators*, Adv. Math. Phys. 2020, 9563791.
- [31] H. YANG, *Existence and approximate controllability of Riemann-Liouville fractional evolution equations of order with weighted time delay*, Bull. Sci. Math. **187** (2023) 103303.
- [32] C. ZHAI, R. JIANG, *Unique solutions for a new coupled system of fractional differential equations*, Adv. Differ. Equ. 2018, **1** (2018).
- [33] C. ZHAI, J. REN, *Some properties of sets, fixed point theorems in ordered product spaces and applications to a nonlinear system of fractional differential equations*, Topol. Methods Nonlinear Anal. **49** (2) (2017) 625–645.
- [34] C. ZHAI, F. WANG, *Properties of positive solutions for the operator equation  $Ax = \lambda x$  and applications to fractional differential equations with integral boundary conditions*, Adv. Differ. Equ. 2015, **366** (2015).
- [35] C. ZHAI, L. WANG,  *$\phi - (h, e)$ -concave operators and applications*, J. Math. Anal. Appl. **454** (2) (2017) 571–584.
- [36] C. ZHAI, W. WANG, *Properties of positive solutions for  $m$ -point fractional differential equations on an infinite interval*, Rev. R. Acad. Cienc. Exactas. Fis. Nat. Ser. A. Mat. **113**(2) (2019) 1289–1298.
- [37] C. ZHAI, W. WANG, *Solutions for a system of Hadamard fractional differential equations with integral conditions*, Numer. Funct. Anal. Optim. **41** (2) (2020) 209–229.
- [38] C. ZHAI, X. ZHU, *Unique solution for a new system of fractional differential equations*, Adv. Differ. Equ. 2019, **394** (2019).
- [39] K. ZHANG, Z. FU, *Solutions for a class of Hadamard fractional boundary value problems with sign-changing nonlinearity*, J. Funct. Spaces, 2019, 9046472.

- [40] N. ZHANG, L. ZHANG, T. LIU, H. LIU, *Uniqueness solution and stability results for singular fractional Riemann-Stieltjes integral boundary problems*, *Bull. Sci. math.* **195** (2024) 103487.
- [41] X. ZHANG, L. LIU, B. WIWATANAPATAPHEE, *The eigenvalue for a class of singular  $p$ -Laplacian fractional differential equations involving the Riemann-Stieltjes integral boundary condition*, *Appl. Math. Comput.* **235** (2014) 412–422.