

Numerical Solution of Nonlinear Fractional Boundary Value Problems [†]

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Abstract. The numerical solution of boundary value problems for nonlinear fractional differential equations is discussed. Using an integral equation reformulation of the boundary value problem, some regularity properties of the exact solution are derived. Based on these properties and spline collocation techniques, the attainable order of convergence of the proposed algorithms is studied, theoretically and numerically.

Keywords: Nonlinear fractional differential equation, Boundary value problem, Caputo derivative, Piecewise polynomial approximation, Graded grid
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INTRODUCTION

This paper concerns with the numerical solution of nonlinear fractional boundary value problems of the form

$$(D_t^\alpha y)(t) = f(t, y(t)), \quad 0 \leq t \leq b, \quad 0 < \alpha < 1, \quad y_0 y(0) + y_1 y(b_1) = \gamma, \quad 0 < b_1 \leq b, \quad (1)$$

where $b, b_1, y_0, y_1, \gamma \in \mathbf{R} = (-\infty, \infty)$, $f: [0, b] \times \mathbf{R} \rightarrow \mathbf{R}$ is a given continuous function, $y: [0, b] \rightarrow \mathbf{R}$ is a function to be determined, and $D_t^\alpha y$ is the α -th order Caputo fractional derivative of y with starting point zero. The Caputo differentiation operator D_t^α of order $\alpha \in (0, 1)$ is defined by the formula (see, e.g., [1])

$$(D_t^\alpha y)(t) = \frac{d}{dt} (J^{1-\alpha} [y - y(0)])(t), \quad 0 \leq t \leq b.$$

Here J^λ , the Riemann–Liouville integral operator, is defined for $\lambda > 0$ by

$$(J^\lambda y)(t) = \frac{1}{\Gamma(\lambda)} \int_0^t (t-s)^{\lambda-1} y(s) ds, \quad t > 0, \quad (2)$$

with Γ , the Euler Gamma function. It is well known (see, e.g., [2]) that J^λ for $\lambda > 0$ is linear, bounded and compact as an operator from $L^\infty(0, b)$ into $C[0, b]$. Moreover (see, e.g., [3]), we have for any $y \in L^\infty(0, b)$ that $J^\lambda y \in C[0, b]$, $(J^\lambda y)(0) = 0$ and $D_t^\beta J^\lambda y = J^{\lambda-\beta} y$, $0 < \beta \leq \lambda$ (we set $J^0 = I$ where I is the identity mapping). For existence of a solution of problem (1) see, for example, [1, 8].

In last decades it has been observed an increasing interest in the study of fractional differential equations (see, e.g., [1, 3, 4, 5, 6, 8]). In [5] spline approximations for solving linear fractional boundary value problems have been used. The purpose of the current contribution is to extend the main results of [5] to nonlinear fractional boundary value problems of the form (1) in a situation where the derivatives of the function $f(t, y)$ may be unbounded at $t = 0$.

SMOOTHNESS OF THE SOLUTION

Let $y \in C[0, b]$ be such that $D_t^\alpha y \in C[0, b]$. Introduce a new unknown function $z = D_t^\alpha y$. Then (see, e.g. [1, 3])

$$y(t) = (J^\alpha z)(t) + d, \quad t \in [0, b], \quad (3)$$

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