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Functional Differential Equations with Causal Operators

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Abstract: The aim of this paper is to established the existence of solutions and some properties of set solutions for a class of functional differential equation with causal operator under assumption that the equation satisfies the Carathéodory type condition.

Keywords: functional differential equation; causal operator; existence results

1 Introduction

The study of differential equations with causal operators has a rapid development in the last years and some results are assembled in a recent monograph [1]. The term of causal operators is adopted from engineering literature and the theory these operators has the powerful quality of unifying ordinary differential equations, integro - differential equations, differential equations with finite or infinite delay, Volterra integral equations, and neutral functional equations, to name a few.

In the paper [6] is considered the class $\mathcal{S}$ of all infinite - dimensional nonlinear M- input u, M- output y systems (ρ, f, g, Q) given by the following controlled nonlinear functional equation

$$\begin{cases} y'(t) = f(p(t), (\widetilde{Q}y)(t)) + g(p(t), (\widetilde{Q}y)(t), u(t)) \\ y|_{[-\sigma,0]} = y^0 \in C([-\sigma, 0], \mathbb{R}^M) \end{cases}, \tag{1}$$

where $\sigma \geq 0$ quantifies the memory of the system, p is a perturbation term, and $\widetilde{Q}$ is a nonlinear causal operator. The aim of the control objective is the development of a adaptive servomechanism which ensures practical tracking, by the system output, of an arbitrary reference signal assumed to be in the class $\mathcal{R}$ of all locally absolutely continuous and bounded with essentially bounded derivative.

More exactly, the control objective is to determine an $(\mathcal{R}, \mathcal{S})-$ servomechanism, that is, to determine the continuous functions $\Phi : \mathbb{R}^M \to \mathbb{R}^M$ and $\psi_\lambda : \mathbb{R}_+ \to \mathbb{R}_+$ (parametrized by $\lambda > 0$) such that, for every system of class $\mathcal{S}$ and every reference signal $r \in \mathcal{R}$, the control

$$u(t) = -k(t)\Phi(y(t) - r(t)), \ \dot{k}(t) = \psi_\lambda(\|y(t) - r(t)\|), \ k|_{[-\sigma,0]} = k^0, \tag{2}$$

applied to (1) ensures convergence of controller gain,and tracking of $r(\cdot)$ with asymptotic accuracy quantified by $\lambda > 0$, in the sense that $\limsup\{\|y(t) - r(t)\| - \lambda, 0\} \to 0$ as $t \to \infty$. For more details (see [6, 10]).

Using (2), we can write (1) as

$$x'(t) = F(t, (Qx)(t)), \ x|_{[-\sigma,0]} = x^0 \in C([-\sigma, 0], \mathbb{R}^N), \tag{3}$$

where $N = M + 1$, $x(t) := (y(t), k(t))$, $x^0 = (y^0, k^0)$, and Q is an operator defined on $C([-\sigma, 0], \mathbb{R}^N)$ by

$$(Qx)(t) = (Q(y, k))(t) := ((\widetilde{Q}y)(t), y(t), k(t)).$$

The purpose of this article is to study the topological properties of the initial value peoblem (3). For this we will use ideas from papers [4], [5]. Also, we give an existence result for this problem, assuming only the continuity of the operator Q. In the paper [6] is also obtained an existence result assuming that the operator Q is a locally Lipschitz operator.

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