Optimal Control of Nonlinear Systems Using the Homotopy Perturbation Method

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Abstract—This paper presents a new method for solving a class of nonlinear optimal control problems with a quadratic performance index. In this method, first the original optimal control problem is transformed into a nonlinear two-point boundary value problem (TPBVP) via the Pontryagin's maximum principle. Then, using the Homotopy Perturbation Method (HPM) and introducing a convex homotopy in topologic space, the nonlinear TPBVP is transformed into a sequence of linear time-invariant TPBVP's. By solving the presented linear TPBVP sequence in a recursive manner, the optimal control law and the optimal trajectory are determined in the form of infinite series. Finally, in order to obtain an accurate enough suboptimal control law, an iterative algorithm with low computational complexity is introduced. An illustrative example demonstrates the simplicity and efficiency of proposed method.

Index Terms—nonlinear optimal control problem, Pontryagin's maximum principle, two-point boundary value problem, Homotopy Perturbation Method

I. INTRODUCTION

Theory and application of optimal control has been widely used in different fields such as biomedicine [1], aircraft systems [2], robotic [3], etc. However, optimal control of nonlinear systems is a challenging task which has been studied extensively for decades.

Methods of solving nonlinear optimal control problems (OCP's) can be divided into two categories. The first category, which contains direct methods, converts the problem into a nonlinear programming by using the discretization or parameterization techniques [4-5]. The second category contains indirect methods and leads to the Hamilton-Jacobi-Bellman (HJB) equation, based on dynamic programming [6], or nonlinear two-point boundary value problem (TPBVP), based on the Pontryagin's maximum principle [7]. In general, the HJB equation is a nonlinear partial differential equation that is hard to solve in most cases. An excellent literature review on the methods for approximating the solution of HJB

equation is provided in [8]. Besides, nonlinear TPBVP has no analytical solution except for a few simple cases. Thus, many researches have been devoted to find an approximate solution for the nonlinear TPBVP's. Recently, successive approximation approach (SAA) and sensitivity approach have been introduced in [9] and [10], respectively. In those, a sequence of nonhomogeneous linear time-varying TPBVP's is solved instead of directly solving the nonlinear TPBVP derived from the Pontryagin's maximum principle. However, solving time-varying equations is much more difficult than solving time-invariant ones.

The Homotopy Perturbation Method (HPM) was initially proposed by the Chinese mathematician J. H. He [11-12]. This method has been widely used to solve nonlinear problems in different fields [13-15]. In contrast to the perturbation method [16], the HPM is independent upon small/large physical parameters in system model. However, like the other traditional non-perturbation methods such as the Lyapunov's artificial small parameter method [17] and Adomian's decomposition method [18], uniformly convergence of the solution series obtained via the HPM can not be ensured.

In this paper, based on the HPM, a new method is proposed to solve a class of nonlinear OCP's. In this method, first the original nonlinear OCP is transformed into a nonlinear TPBVP by using the maximum principle. Applying the HPM transforms the nonlinear TPBVP into a sequence of linear time-invariant TPBVP's. Solving the proposed linear TPBVP sequence in a recursive manner leads to the optimal control law and the optimal trajectory in the form of infinite series. The proposed method avoids the trouble of directly solving the nonlinear TPBVP or the HJB equation. In addition, it avoids solving a sequence of linear time-varying TPBVP's. It only requires solving a sequence of linear time-invariant TPBVP's. Hence, it reduces the computational complexity, effectively. The rest of paper is organized as follows. In section 2 the statement of problem is discussed. Section 3 elaborates the

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Ying-Ying Zheng

Optimal Control Of Nonlinear Systems Using The Homotopy:
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