Optimal Control of Nonlinear Systems Using the Homotopy Perturbation Method

Amin Jajarmi
Department of Electrical Engineering
Ferdowsi University of Mashhad
Mashhad, Iran
jajarmi@stu-mail.um.ac.ir

Hamidreza Ramezanpour
Department of Nuclear Engineering and Physics
Amirkabir University of Technology
Tehran, Iran
h.ramezanpour@aut.ac.ir

Arman Sargolzaei, Pouyan Shafaei
Department of Electrical Engineering
Sadjad Institute of Higher Education
Mashhad, Iran
a.sargolzaei@ieee.org, pouyan.shafaei@gmail.com

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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M Lipman

Optimal Control Of Nonlinear Systems Using The Homotopy:

Deep Reinforcement Learning with Guaranteed Performance Yinyan Zhang,Shuai Li,Xuefeng Zhou,2019-11-09 This book discusses methods and algorithms for the near optimal adaptive control of nonlinear systems including the corresponding theoretical analysis and simulative examples and presents two innovative methods for the redundancy resolution of redundant manipulators with consideration of parameter uncertainty and periodic disturbances It also reports on a series of systematic investigations on a near optimal adaptive control method based on the Taylor expansion neural networks estimator design approaches and the idea of sliding mode control focusing on the tracking control problem of nonlinear systems under different scenarios The book culminates with a presentation of two new redundancy resolution methods one addresses adaptive kinematic control of redundant manipulators and the other centers on the effect of periodic input disturbance on redundancy resolution Each self contained chapter is clearly written making the book accessible to graduate students as well as academic and industrial researchers in the fields of adaptive and optimal control robotics and dynamic neural networks   Computational Optimal Control Dr Subchan Subchan,Dr Rafal Zbikowski,2009-08-19 Computational Optimal Control Tools and Practice provides a detailed guide to informed use of computational optimal control in advanced engineering practice addressing the need for a better understanding of the practical application of optimal control using computational techniques Throughout the text the authors employ an advanced aeronautical case study to provide a practical real life setting for optimal control theory This case study focuses on an advanced real world problem known as the terminal bunt manoeuvre or special trajectory shaping of a cruise missile Representing the many problems involved in flight dynamics practical control and flight path constraints this case study offers an excellent illustration of advanced engineering practice using optimal solutions The book describes in practical detail the real and tested optimal control software examining the advantages and limitations of the technology Featuring tutorial insights into computational optimal formulations and an advanced case study approach to the topic Computational Optimal Control Tools and Practice provides an essential handbook for practising engineers and academics interested in practical optimal solutions in engineering Focuses on an advanced real world aeronautical case study examining optimisation of the bunt manoeuvre Covers DIRCOL NUDOCCCS PROMIS and SOCS under the GESOP environment and BNDSCO Explains how to configure and optimize software to solve complex real world computational optimal control problems Presents a tutorial three stage hybrid approach to solving optimal control problem formulations   Analysis and Control of Nonlinear Systems Christopher I. Byrnes,Clyde Martin,Richard Saeks,1988   Applied Mechanics Reviews ,1994   **Proceedings of the 1993 American Control Conference** ,1993   *Scientific and Technical Aerospace Reports* ,1994   Proceedings of the ... American Control Conference ,1992   *Role of Nutrients in Neurological Disorders* Senthilkumar Rajagopal,Saravanan Ramachandran,Geethalakshmi Sundararaman,Swarnalatha Gadde Venkata,2022-03-12 This book provides the latest research

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