

# 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 (NOCVP'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], uniform 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

# Optimal Control Of Nonlinear Systems Using The Homotopy

**R Bogdan**



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web the imo has developed a range of training courses to address all aspects of oil spill planning response and management these are known as the oprc model courses these courses have been designed and developed by an international group of experts from governments and industry

**e course booklet on marine accident and** - Oct 05 2022

web this intensive course based on imo model course 3 11 is aimed at assisting the national marine accident investigation authorities in ensuring uniformity and consistency when carrying out investigations into marine casualties and incidents

**imo lms all courses international maritime organization** - Mar 10 2023

web 25 years ago imo developed four training courses to address various aspects of oil spill response planning preparedness and management these are known as the oprc model courses and have been completed by many individuals around the world who are responsible for the oversight and management of an effective response to a marine oil

*port state control imssea* - Jan 08 2023

web this course based on imo model course 3 09 is designed for government technical officials particularly ship surveyors masters chief officers chief and second engineers who are authorized or to be authorized by their relevant governments to execute port state control psc in accordance with the relevant provisions of imo conventions

**international convention on standards of training certification imo** - Dec 07 2022

web imo model courses maritime administrations maritime training institutes stcw f convention

*imo model courses* - Jun 13 2023

web Élément humain imo model courses the programme of model training courses developed out of suggestions from a number of imo member governments following the adoption of the international convention on standards of training certification and watchkeeping for seafarers stcw 1978 as amended

company security officer cso training course dnv - Jun 01 2022

web objectives provision of internationally recognised training for qualification as company security officer cso in accordance with the standard of competence as outlined in the guidelines on training and certification for company security officers issued as annex of msc circ 1154 and the imo model course 3 20

**train the trainer for the maritime industry dnv** - Aug 03 2022

web the course incorporates important elements of the imo model course 6 09 training course for instructors in order to preserve a high quality learning environment the number of participants is limited to 10 the course focuses on training requirements of stcw solas marpol ism and isps code the importance of objectives and feedback

**imo e learning and training** - Dec 27 2021

web these e learning courses hosted by imo have been carefully designed and would be regularly updated to meet the changing needs of the maritime industry and cover a wide range of topics for the list of available courses and information on the registration process please click here

**model english digital model course title not stcw if** - Jan 28 2022

web encl 5 list of imo model courses model english digital model course title not stcw if in red and struck course 101 training for oil and chemical tanker cargo ops 2014 102 advanced training for oil tanker cargo ops 2015 ed 103 adv training for chemical tanker cargo ops 2016 104 basic training for lgt cargo operations 2014