

H_∞ control design for non-linear distributed parameter systems with mobile actuators and sensors

Xiao-Wei Zhang¹, Huai-Ning Wu¹ 

¹The Science and Technology on Aircraft Control Laboratory, School of Automation Science and Electrical Engineering, Beihang University (Beijing University of Aeronautics and Astronautics), Beijing 100191, People's Republic of China

✉ E-mail: wfn@buaa.edu.cn

Abstract: This study deals with the H_∞ control design problem for a class of non-linear distributed parameter systems described by parabolic partial differential equations (PDEs) via mobile collocated actuators and sensors. Initially, the spatial domain is decomposed into multiple subdomains according to the number of actuator/sensor pairs and the projection modification algorithm is employed to guarantee each actuator/sensor pair is only capable of moving within the respective subdomain. Subsequently, the well-posedness of the closed-loop PDE system is analysed by means of the operator semigroup theory. Then, a control-plus-guidance design method for the non-linear PDE system is developed in the form of bilinear matrix inequalities, such that the resulting closed-loop system is exponentially stable while satisfying a prescribed H_∞ performance of disturbance attenuation, and the mobile actuator/sensor guidance can enhance the transient performance of the closed-loop system. Finally, a numerical example and a practical application example are respectively given to show the effectiveness of the proposed design method.

1 Introduction

Over the past several decades, several research studies have been carried out for the modelling, analysis and control design of distributed parameter systems [1–6], which are usually represented by partial differential equations (PDEs). Especially, the control design of parabolic PDE systems describing lots of industrial processes, such as thermal, fluid flow and chemical reactor processes, has been investigated widely via early lumping or late lumping. For example, in [7, 8], the standard Galerkin method was initially used for linear parabolic PDE systems to derive an approximate model described by ordinary differential equations, which was the basis for the finite-dimensional controller design subsequently. Via the singular perturbation formulation of Galerkin method, the neural-network-based control design and the H_∞ sampled-data fuzzy control design were respectively studied for non-linear parabolic PDE systems in [9, 10]. On the other hand, a few control methods based on the original PDE model were also proposed for parabolic PDE systems. For instance, a sampled-data controller [11] and a distributed event-triggered controller [12] were designed for non-linear parabolic PDE systems, respectively. By the Volterra integral transformation, the backstepping boundary control approaches were developed for linear parabolic PDEs [13, 14] and linear reaction-diffusion parabolic PDEs cascaded with a heat equation [15]. In [16], the exponential stabilisation design problem was addressed for non-linear parabolic PDE systems, whereas finite number of local collocated actuators and sensors are intermittently distributed in space. More recently, by means of the non-collocated local piecewise observation, the local piecewise control design method has been proposed for linear parabolic PDE systems [17]. However, it should be pointed out that the mentioned results above were developed for parabolic PDE systems by adopting a finite number of actuators and sensors fixed at the boundary or certain interior positions of the spatial domain.

In the past few years, there has been rapidly growing interest in the employment of mobile actuators and sensors for the control design of parabolic PDE systems [18–20]. Compared with the static ones, the mobile actuators and sensors have better environmental coverage ability, more active information acquisition ability and stronger control ability. Therefore, using the mobile actuators and sensors to deal with the control design of

parabolic PDE systems is of practical importance. In particular, to improve the closed-loop state response speed, the Lyapunov stability theory has been used to address the guidance design problem of mobile actuators and sensors [21, 22]. In [21], the guidance laws of the collocated mobile actuators and sensors in linear parabolic PDE systems were designed. Further, in [22], a design method of adaptive control plus mobile guidance was provided for two-dimensional (2D) linear parabolic PDE systems utilising mobile collocated actuator/sensor pairs with augmented vehicle dynamics. However, the results in [21, 22] were all developed for linear parabolic PDE systems and did not consider the effect of external disturbances on the systems in controller design. To the best of the authors' knowledge, using mobile actuators and sensors to deal with the H_∞ control design problem for non-linear parabolic PDE systems under external disturbances has not been addressed yet, which motivates this work.

In this work, we will investigate the H_∞ control problem for non-linear parabolic PDE systems under external disturbances using mobile collocated actuators and sensors. Initially, a control design scheme based on mobile actuator/sensor pairs is proposed for the non-linear parabolic PDE system, where the spatial domain is decomposed into multiple subdomains according to the number of actuator/sensor pairs and the projection modification algorithm in the robust adaptive control literature is employed to ensure each collocated actuator/sensor pair only can move within the respective subdomain divided in advance. Subsequently, via the operator semigroup theory, the well-posedness of the closed-loop PDE system is discussed. Then, by using Lyapunov direct technique, a control-plus-guidance design method for the PDE system is developed in terms of bilinear matrix inequalities (BMIs), such that the resulting closed-loop system is exponentially stable in the sense of \mathcal{R}^∞ -norm while satisfying a prescribed H_∞ performance of disturbance attenuation, and the mobile actuator/sensor guidance can enhance the transient performance of the closed-loop system. Moreover, a linear matrix inequality (LMI) iterative algorithm is proposed to solve the BMIs. Finally, two examples are presented to illustrate the effectiveness of the proposed design method.

The novelty and main contribution of this paper can be summarised as follows: (i) The projection modification algorithm in the robust adaptive control literature is used to guarantee each

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Control Of Nonlinear Distributed Parameter Systems

Yicheng Fang



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Control Of Nonlinear Distributed Parameter Systems Goong Chen, 2001 An examination of progress in mathematical control theory applications It provides analyses of the influence and relationship of nonlinear partial differential equations to control systems and contains state of the art reviews including presentations from a conference co sponsored by the National Science Foundation the Institute of Mathematics and its Applications the University of Minnesota and Texas A M University

Control Of Nonlinear Distributed Parameter Systems Goong Chen, Irena Lasiecka, Jianxin Zhou, 2001-03-14 An examination of progress in mathematical control theory applications It provides analyses of the influence and relationship of nonlinear partial differential equations to control systems and contains state of the art reviews including presentations from a conference co sponsored by the National Science Foundation the Institute of Mathematics and its Applications the University of Minnesota and Texas A M University

Control of Nonlinear Distributed Parameter Systems With Application to Flow Control, 1992 The goal of this project was to put the intuitive idea of gain scheduling on a rigorous foundation for a class of nonlinear distributed parameter systems This involved a study of the existence and characterization of the ideal infinite dimensional feedback control Since in most applications the feedback function cannot be computed in closed form it was necessary to study the convergence of approximate feedback functions based on increasingly higher order finite dimensional approximations of the system to the ideal function Finally the results were applied to Burgers Equation which can be viewed as a low order approximation to a wide variety of physical phenomena including viscous compressible flow

Spatio-Temporal Modeling of Nonlinear Distributed Parameter Systems Han-Xiong Li, Chenkun Qi, 2011-02-24 The purpose of this volume is to provide a brief review of the previous work on model reduction and identification of distributed parameter systems DPS and develop new spatio temporal models and their relevant identification approaches In this book a systematic overview and classification on the modeling of DPS is presented first which includes model reduction parameter estimation and system identification Next a class of block oriented nonlinear systems in traditional lumped parameter systems LPS is extended to DPS which results in the spatio temporal Wiener and Hammerstein systems and their identification methods Then the traditional Volterra model is extended to DPS which results in the spatio temporal Volterra model and its identification algorithm All these methods are based on linear time space separation Sometimes the nonlinear time space separation can play a better role in modeling of very complex processes Thus a nonlinear time space separation based neural modeling is also presented for a class of DPS with more complicated dynamics Finally all these modeling approaches are successfully applied to industrial thermal processes including a catalytic rod a packed bed reactor and a snap curing oven The work is presented giving a unified view from time space separation The book also illustrates applications to thermal processes in the electronics packaging and chemical industry This volume assumes a basic knowledge about distributed parameter systems system modeling and identification It is intended for researchers graduate students and

engineers interested in distributed parameter systems nonlinear systems and process modeling and control

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Data-Driven Spatiotemporal Modeling and Control of Nonlinear Distributed Parameter Systems and Their Applications Bowen Xu, Xinjiang Lu, 2026-01-01 This book provides a systematic overview and classification on modeling and control of different types of Distributed Parameter Systems DPSs and develops new methods to tackle some of these unsolved problems facilitating a better understanding of DPSs and providing references for practical problem solving in the relevant fields All these methods presented in this book are verified by specific scenarios It is worth mentioning that in the context of disciplinary integration and artificial intelligence the research ideas methods and models in this book can be further integrated and developed From application perspectives they can also extend from traditional mechanical electrical and chemical fields to emerging fields of new energy new materials and multimodal information Under the background of disciplinary integration and the development of artificial intelligence the book will be beneficial to undergraduate and postgraduate students in interdisciplinary disciplines including manufacturing engineering mechanical engineering electrical engineering computer engineering and control engineering etc It is also intended for researchers and practical users in the fields of nonlinear dynamics spatiotemporal modeling and intelligent control

Control and Estimation of Distributed Parameter Systems Wolfgang Desch, F. Kappel, Karl Kunisch, 1994 A semigroup formulation of a nonlinear size structured distributed rate population model Damage detection and characterization in smart material structures Optimality conditions for non qualified parabolic control problems Convergence of trajectories for a controlled viscous Burgers equation Optimality conditions for boundary control problems of parabolic type Pontryagin's principle for optimal control problems governed by semilinear elliptic equations Invariance of the Hamiltonian in control problems for semilinear parabolic distributed parameter systems Rate distribution modeling for structured heterogeneous populations A model for a two layered plate with interfacial slip Numerical solution of a constrained control problem for a phase field model Uniform stabilizability of nonlinearly coupled Kirchhoff plate equations Boundary temperature control for thermally coupled Navier Stokes equations Adaptive estimation of nonlinear distributed parameter systems Decay estimates for the wave equation with internal damping On the controllability of the rotation of a flexible arm Modeling and controllability of interconnected elastic membranes On feedback controls for dynamic networks of strings and beams and their numerical simulation Various relaxations in optimal control of distributed parameter systems Convergence of an SQP method for a class of nonlinear parabolic boundary control problems Conditional stability in

determination of densities of heat sources in a bounded domain Boundary stabilization of the Korteweg de Vries equation Controllability of the linear system of thermoelasticity Dirichlet Neumann boundary conditions **Optimal Control of a Class of Nonlinear Distributed Parameter Systems** Tian-Shen Tang,1990 *Control and Estimation of Distributed Parameter Systems: Nonlinear Phenomena* Wolfgang Desch,Franz Kappel,Karl Kunisch,2011-09-30 22 papers on control of nonlinear partial differential equations highlight the area from a broad variety of viewpoints They comprise theoretical considerations such as optimality conditions relaxation or stabilizability theorems as well as the development and evaluation of new algorithms A significant part of the volume is devoted to applications in engineering continuum mechanics and population biology **Sliding mode control of nonlinear first order distributed parameter systems** Hebertt J. Sira Ramírez,Jesús Rivero-Mendoza,1990 *Recent Advances in Control of Nonlinear and Distributed Parameter Systems, Robust Control, and Aerospace Control Applications* ,1988 Estimation Techniques for Distributed Parameter Systems H.T. Banks,K. Kunisch,2012-12-06 The research detailed in this monograph was originally motivated by our interest in control problems involving partial and delay differential equations Our attempts to apply control theory techniques to such problems in several areas of science convinced us that in the need for better and more detailed models of distributed continuum processes in biology and mechanics lay a rich interesting and challenging class of fundamental questions These questions which involve science and mathematics are typical of those arising in inverse or parameter estimation problems Our efforts on inverse problems for distributed parameter systems which are infinite dimensional in the most common realizations began about seven years ago at a time when rapid advances in computing capabilities and availability held promise for significant progress in the development of a practically useful as well as theoretically sound methodology for such problems Much of the research reported in our presentation was not begun when we outlined the plans for this monograph some years ago By publishing this monograph now when only a part of the originally intended topics are covered see Chapter VII in this respect we hope to stimulate the research and interest of others in an area of scientific endeavor which has exceeded even our optimistic expectations with respect to excitement opportunity and stimulation The computer revolution alluded to above and the development of new codes allow one to solve rather routinely certain estimation problems that would have been out of the question ten years ago Identification and Control of Non-linear Distributed Parameter Systems Satyam Godasi,2002 **Control of Distributed Parameter Systems** S. P. Banks,A. J. Pritchard,2014-05-18 Control of Distributed Parameter Systems covers the proceedings of the Second IFAC Symposium Coventry held in Great Britain from June 28 to July 1 1977 The book focuses on the methodologies processes and techniques in the control of distributed parameter systems including boundary value control digital transfer matrix and differential equations The selection first discusses the asymptotic methods in the optimal control of distributed systems applications of distributed parameter control theory of a survey and dual variational inequalities for external eigenvalue problems The book

also ponders on stochastic differential equations in Hilbert space and their application to delay systems and linear quadratic optimal control problem over an infinite time horizon for a class of distributed parameter systems The manuscript investigates the semigroup approach to boundary value control and stability of nonlinear distributed parameter systems Topics include boundary control action implemented through a dynamical system classical boundary value controls stability of nonlinear systems and feedback control on the boundary The text also focuses on the functional analysis interpretation of Lyapunov stability method of multipliers for a class distributed parameter systems and digital transfer matrix approach to distributed system simulation The selection is a dependable source of data for readers interested in the control of distributed parameter systems

Applied Optimal Control Theory of Distributed Systems K.A. Lurie, 2013-11-21 This book represents an extended and substantially revised version of my earlier book *Optimal Control in Problems of Mathematical Physics* originally published in Russian in 1975 About 60% of the text has been completely revised and major additions have been included which have produced a practically new text My aim was to modernize the presentation but also to preserve the original results some of which are little known to a Western reader The idea of composites which is the core of the modern theory of optimization was initiated in the early seventies The reader will find here its implementation in the problem of optimal conductivity distribution in an MHD generator channel flow Since then it has emerged into an extensive theory which is undergoing a continuous development The book does not pretend to be a textbook neither does it offer a systematic presentation of the theory Rather it reflects a concept which I consider as fundamental in the modern approach to optimization of distributed systems Bibliographical notes though extensive do not pretend to be exhaustive as well My thanks are due to Professor Jean Louis Armand and Professor Wolf Stadler whose friendly assistance in translating and polishing the text was so valuable I am indebted to Mrs Kathleen Durand and Mrs Colleen Lewis for the hard job of typing large portions of the manuscript

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