

Adaptive Control of Parabolic PDEs

Andrey Smyshlyaev & Miroslav Krstic

Adaptive Control Of Parabolic Pdes

Han-Xiong Li,Chenkun Qi



Adaptive Control Of Parabolic Pdes:

Adaptive Control of Parabolic PDEs Andrey Smyshlyaev, Miroslav Krstic, 2010-07-01 This book introduces a comprehensive methodology for adaptive control design of parabolic partial differential equations with unknown functional parameters including reaction convection diffusion systems ubiquitous in chemical thermal biomedical aerospace and energy systems Andrey Smyshlyaev and Miroslav Krstic develop explicit feedback laws that do not require real time solution of Riccati or other algebraic operator valued equations The book emphasizes stabilization by boundary control and using boundary sensing for unstable PDE systems with an infinite relative degree The book also presents a rich collection of methods for system identification of PDEs methods that employ Lyapunov passivity observer based swapping based gradient and least squares tools and parameterizations among others Including a wealth of stimulating ideas and providing the mathematical and control systems background needed to follow the designs and proofs the book will be of great use to students and researchers in mathematics engineering and physics It also makes a valuable supplemental text for graduate courses on distributed parameter systems and adaptive control

Adaptive Control of Hyperbolic PDEs Henrik Anfinssen, Ole Morten Aamo, 2019-02-21 Adaptive Control of Linear Hyperbolic PDEs provides a comprehensive treatment of adaptive control of linear hyperbolic systems using the backstepping method It develops adaptive control strategies for different combinations of measurements and actuators as well as for a range of different combinations of parameter uncertainty The book treats boundary control of systems of hyperbolic partial differential equations PDEs with uncertain parameters The authors develop designs for single equations as well as any number of coupled equations The designs are accompanied by mathematical proofs which allow the reader to gain insight into the technical challenges associated with adaptive control of hyperbolic PDEs and to get an overview of problems that are still open for further research Although stabilization of unstable systems by boundary control and boundary sensing are the particular focus state feedback designs are also presented The book also includes simulation examples with implementational details and graphical displays to give readers an insight into the performance of the proposed control algorithms as well as the computational details involved A library of MATLAB code supplies ready to use implementations of the control and estimation algorithms developed in the book allowing readers to tailor controllers for cases of their particular interest with little effort These implementations can be used for many different applications including pipe flows traffic flow electrical power lines and more Adaptive Control of Linear Hyperbolic PDEs is of value to researchers and practitioners in applied mathematics engineering and physics it contains a rich set of adaptive control designs including mathematical proofs and simulation demonstrations The book is also of interest to students looking to expand their knowledge of hyperbolic PDEs

Traffic Congestion Control by PDE Backstepping Huan Yu, Miroslav Krstic, 2022-12-16 This monograph explores the design of controllers that suppress oscillations and instabilities in congested traffic flow using PDE backstepping methods The first part of the text is concerned with basic backstepping control of

freeway traffic using the Aw Rascle Zhang ARZ second order PDE model It begins by illustrating a basic control problem suppressing traffic with stop and go oscillations downstream of ramp metering before turning to the more challenging case for traffic upstream of ramp metering The authors demonstrate how to design state observers for the purpose of stabilization using output feedback control Experimental traffic data are then used to calibrate the ARZ model and validate the boundary observer design Because large uncertainties may arise in traffic models adaptive control and reinforcement learning methods are also explored in detail Part II then extends the conventional ARZ model utilized until this point in order to address more complex traffic conditions multi lane traffic multi class traffic networks of freeway segments and driver use of routing apps The final chapters demonstrate the use of the Lighthill Whitham Richards LWR first order PDE model to regulate congestion in traffic flows and to optimize flow through a bottleneck In order to make the text self contained an introduction to the PDE backstepping method for systems of coupled first order hyperbolic PDEs is included Traffic Congestion Control by PDE Backstepping is ideal for control theorists working on control of systems modeled by PDEs and for traffic engineers and applied scientists working on unsteady traffic flows It will also be a valuable resource for researchers interested in boundary control of coupled systems of first order hyperbolic PDEs

PDE Control of String-Actuated Motion Ji Wang, Miroslav Krstic, 2022-10-25 New adaptive and event triggered control designs with concrete applications in undersea construction offshore drilling and cable elevators Control applications in undersea construction cable elevators and offshore drilling present major methodological challenges because they involve PDE systems cables and drillstrings of time varying length coupled with ODE systems the attached loads or tools that usually have unknown parameters and unmeasured states In PDE Control of String Actuated Motion Ji Wang and Miroslav Krstic develop control algorithms for these complex PDE ODE systems evolving on time varying domains Motivated by physical systems the book s algorithms are designed to operate with rigorous mathematical guarantees in the presence of real world challenges such as unknown parameters unmeasured distributed states environmental disturbances delays and event triggered implementations The book leverages the power of the PDE backstepping approach and expands its scope in many directions Filled with theoretical innovations and comprehensive in its coverage PDE Control of String Actuated Motion provides new design tools and mathematical techniques with far reaching potential in adaptive control delay systems and event triggered control

Dynamics and Control of Mechanical Systems in Offshore Engineering Wei He, Shuzhi Sam Ge, Bernard Voon Ee How, Yoo Sang Choo, 2013-10-02 Dynamics and Control of Mechanical Systems in Offshore Engineering is a comprehensive treatment of marine mechanical systems MMS involved in processes of great importance such as oil drilling and mineral recovery Ranging from nonlinear dynamic modeling and stability analysis of flexible riser systems through advanced control design for an installation system with a single rigid payload attached by thrusters to robust adaptive control for mooring systems it is an authoritative reference on the dynamics and control of MMS Readers will gain not only a complete picture of MMS at the

system level but also a better understanding of the technical considerations involved and solutions to problems that commonly arise from dealing with them. The text provides a complete framework of dynamical analysis and control design for marine mechanical systems, new results on the dynamical analysis of riser mooring and installation systems together with a general modeling method for a class of MMS, a general method and strategy for realizing the control objectives of marine systems with guaranteed stability, the effectiveness of which is illustrated by extensive numerical simulation and approximation based control schemes using neural networks for installation of subsea structures with attached thrusters in the presence of time varying environmental disturbances and parametric uncertainties. Most of the results presented are analytical, with repeatable design algorithms with proven closed loop stability and performance analysis of the proposed controllers is rigorous and detailed. *Dynamics and Control of Mechanical Systems in Offshore Engineering* is primarily intended for researchers and engineers in the system and control community but graduate students studying control and marine engineering will also find it a useful resource as will practitioners working on the design, running or maintenance of offshore platforms.

Delay Compensation for Nonlinear, Adaptive, and PDE Systems Miroslav Krstic, 2010-01-23. Some of the most common dynamic phenomena that arise in engineering practice, actuator and sensor delays, fall outside the scope of standard finite dimensional system theory. The first attempt at infinite dimensional feedback design in the field of control systems, the Smith predictor, has remained limited to linear finite dimensional plants over the last five decades. Shedding light on new opportunities in predictor feedback, this book significantly broadens the set of techniques available to a mathematician or engineer working on delay systems. The book is a collection of tools and techniques that make predictor feedback ideas applicable to nonlinear systems, systems modeled by PDEs, systems with highly uncertain or completely unknown input/output delays, and systems whose actuator or sensor dynamics are modeled by more general hyperbolic or parabolic PDEs rather than by pure delay. Numerous examples and a detailed treatment of individual classes of problems will help the reader master the techniques. *Delay Compensation for Nonlinear Adaptive and PDE Systems* is an excellent reference guide for graduate students, researchers, and professionals in mathematics, systems control, as well as chemical, mechanical, electrical, computer, aerospace, and civil structural engineering. Parts of the book may be used in graduate courses on general distributed parameter systems, linear delay systems, PDEs, nonlinear control, state estimator and observers, adaptive control, robust control, or linear time varying systems.

The Control Handbook (three volume set) William S. Levine, 2018-10-08. At publication, *The Control Handbook* immediately became the definitive resource that engineers working with modern control systems required. Among its many accolades, that first edition was cited by the AAP as the Best Engineering Handbook of 1996. Now 15 years later, William Levine has once again compiled the most comprehensive and authoritative resource on control engineering. He has fully reorganized the text to reflect the technical advances achieved since the last edition and has expanded its contents to include the multidisciplinary perspective that is making control

engineering a critical component in so many fields Now expanded from one to three volumes The Control Handbook Second Edition brilliantly organizes cutting edge contributions from more than 200 leading experts representing every corner of the globe They cover everything from basic closed loop systems to multi agent adaptive systems and from the control of electric motors to the control of complex networks Progressively organized the three volume set includes Control System Fundamentals Control System Applications Control System Advanced Methods Any practicing engineer student or researcher working in fields as diverse as electronics aeronautics or biomedicine will find this handbook to be a time saving resource filled with invaluable formulas models methods and innovative thinking In fact any physicist biologist mathematician or researcher in any number of fields developing or improving products and systems will find the answers and ideas they need As with the first edition the new edition not only stands as a record of accomplishment in control engineering but provides researchers with the means to make further advances

Boundary Control of PDEs Miroslav Krstic, Andrey Smyshlyaev, 2008-09-25 A clear and concise introduction to backstepping an elegant new approach to boundary control of partial differential equations PDEs

The Control Systems Handbook William S. Levine, 2018-10-03 At publication The Control Handbook immediately became the definitive resource that engineers working with modern control systems required Among its many accolades that first edition was cited by the AAP as the Best Engineering Handbook of 1996 Now 15 years later William Levine has once again compiled the most comprehensive and authoritative resource on control engineering He has fully reorganized the text to reflect the technical advances achieved since the last edition and has expanded its contents to include the multidisciplinary perspective that is making control engineering a critical component in so many fields Now expanded from one to three volumes The Control Handbook Second Edition organizes cutting edge contributions from more than 200 leading experts The third volume Control System Advanced Methods includes design and analysis methods for MIMO linear and LTI systems Kalman filters and observers hybrid systems and nonlinear systems It also covers advanced considerations regarding Stability Adaptive controls System identification Stochastic control Control of distributed parameter systems Networks and networked controls As with the first edition the new edition not only stands as a record of accomplishment in control engineering but provides researchers with the means to make further advances Progressively organized the first two volumes in the set include Control System Fundamentals Control System Applications

Materials Phase Change PDE Control & Estimation Shumon Koga, Miroslav Krstic, 2020-11-01 This monograph introduces breakthrough control algorithms for partial differential equation models with moving boundaries the study of which is known as the Stefan problem The algorithms can be used to improve the performance of various processes with phase changes such as additive manufacturing Using the authors innovative design solutions readers will also be equipped to apply estimation algorithms for real world phase change dynamics from polar ice to lithium ion batteries A historical treatment of the Stefan problem opens the book situating readers in the larger context of the area Following this the chapters are organized into two

parts The first presents the design method and analysis of the boundary control and estimation algorithms Part two then explores a number of applications such as 3D printing via screw extrusion and laser sintering and also discusses the experimental verifications conducted A number of open problems and provided as well offering readers multiple paths to explore in future research Materials Phase Change PDE Control Estimation is ideal for researchers and graduate students working on control and dynamical systems and particularly those studying partial differential equations and moving boundaries It will also appeal to industrial engineers and graduate students in engineering who are interested in this area

Boundary Control of PDEs Miroslav Krstic, Andrey Smyshlyaev, 2008-01-01 The text s broad coverage includes parabolic PDEs hyperbolic PDEs of first and second order fluid thermal and structural systems delay systems PDEs with third and fourth derivatives in space including variants of linearized Ginzburg Landau Schrodinger Kuramoto Sivashinsky KdV beam and Navier Stokes equations real valued as well as complex valued PDEs stabilization as well as motion planning and trajectory tracking for PDEs and elements of adaptive control for PDEs and control of nonlinear PDEs

Input-to-State Stability for PDEs Iasson Karafyllis, Miroslav Krstic, 2018-06-07 This book lays the foundation for the study of input to state stability ISS of partial differential equations PDEs predominantly of two classes parabolic and hyperbolic This foundation consists of new PDE specific tools In addition to developing ISS theorems equipped with gain estimates with respect to external disturbances the authors develop small gain stability theorems for systems involving PDEs A variety of system combinations are considered PDEs of either class with static maps PDEs again of either class with ODEs PDEs of the same class parabolic with parabolic and hyperbolic with hyperbolic and feedback loops of PDEs of different classes parabolic with hyperbolic In addition to stability results including ISS the text develops existence and uniqueness theory for all systems that are considered Many of these results answer for the first time the existence and uniqueness problems for many problems that have dominated the PDE control literature of the last two decades including for PDEs that include non local terms backstepping control designs which result in non local boundary conditions Input to State Stability for PDEs will interest applied mathematicians and control specialists researching PDEs either as graduate students or full time academics It also contains a large number of applications that are at the core of many scientific disciplines and so will be of importance for researchers in physics engineering biology social systems and others

Delay-Adaptive Linear Control Yang Zhu, Miroslav Krstic, 2020-04-28 Basic predictor feedback for single input systems Basic idea of adaptive control for single input systems Single input systems with full relative degree Single input systems with arbitrary relative degree Exact predictor feedback for multi input systems Full state feedback of uncertain multi input systems Output feedback of uncertain multi input systems Output feedback of systems with uncertain delays parameters and ODE state Predictor feedback for uncertainty free systems Predictor feedback of uncertain single input systems Predictor feedback of uncertain multi input systems

Control of Turbulent and Magnetohydrodynamic Channel Flows Rafael Vazquez, Miroslav Krstic, 2008 This

monograph presents new constructive design methods for boundary stabilization and boundary estimation for several classes of benchmark problems in flow control with potential applications to turbulence control weather forecasting and plasma control One of the main features of the book is a unique backstepping approach to parabolic partial differential equations which yields not only the stabilization of the flow but also the explicit solvability of the closed loop system The work is an excellent reference for a broad interdisciplinary engineering and mathematics audience control theorists fluid mechanicians mechanical engineers aerospace engineers chemical engineers electrical engineers applied mathematicians as well as research and graduate students in these fields

Boundary Control of Flexible Three-Dimensional Euler-Bernoulli

Beams Ning Ji, Jinkun Liu, 2022-03-24 This book focuses on vibration suppression of flexible three dimensional Euler Bernoulli beams modeled by PDEs Boundary control strategy and several control methods are proposed to stabilize the closed loop system Besides some common engineering problems such as input constraint and output constraint are also considered in the control scheme design This book offers a comprehensive introduction of the modeling process controller design stability analysis and numerical simulation The detailed MATLAB codes in each chapter are also provided which can make readers better understand the control flow of the system This book is mainly targeted for researchers senior undergraduate students and postgraduate students in the field of control theory and control engineering

Vibration

Control Methods of Mechanical Distributed Parameter Systems Xueyan Xing, Jinkun Liu, 2021-05-18 This book aims at investigating PDE modeling and vibration control of some typical mechanical distributed parameter systems Several control methods are proposed to realize stabilization of the closed loop system with the help of mathematical tools and stability analysis methods Besides some common engineering problems such as input and output constraints are also involved in the control design This book offers a comprehensive introduction of mechanical distributed parameter systems including PDE modeling controller design and stability analysis The related fundamental mathematical tools and analytical approaches involving in the PDE modeling and controller are also provided which broadens its reach to readers

Numerical Control:

Part B Emmanuel Trélat, Enrique Zuazua, 2023-02-20 Numerical Control Part B Volume 24 in the Handbook of Numerical Analysis series highlights new advances in the field with this new volume presenting interesting chapters written by an international board of authors Chapters in this volume include Control problems in the coefficients and the domain for linear elliptic equations Computational approaches for extremal geometric eigenvalue problems Non overlapping domain decomposition in space and time for PDE constrained optimal control problems on networks Feedback Control of Time dependent Nonlinear PDEs with Applications in Fluid Dynamics Stabilization of the Navier Stokes equations Theoretical and numerical aspects Reconstruction algorithms based on Carleman estimates and more Other sections cover Discrete time formulations as time discretization strategies in data assimilation Back and forth iterations Time reversal methods Unbalanced Optimal Transport from Theory to Numerics An ADMM Approach to the Exact and Approximate Controllability of

Parabolic Equations Nonlocal balance laws an overview over recent results Numerics and control of conservation laws
 Numerical approaches for simulation and control of superconducting quantum circuits and much more Provides the authority
 and expertise of leading contributors from an international board of authors Presents the latest release in the Handbook of
 Numerical Analysis series Updated release includes the latest information on Numerical Control **Dynamic Modeling
 and Boundary Control of Flexible Axially Moving System** Yu Liu,Fengjiao Liu,Yanfang Mei,Xiangqian Yao,Wei
 Zhao,2023-01-13 The main objectives of the book are to introduce the design method of boundary control strategies for the
 axially moving structures to reduce their vibration This book provides the reader with a thorough grounding in the boundary
 controller design Our goal is to provide advanced boundary controller design methods and their stability analysis methods
 and offer simulation examples and MATLAB programs for each boundary control algorithm For each chapter several
 engineering application examples are given and the contents of each chapter in this book are independent so that readers
 can just read their own needs In this book all the control algorithms and their programs are described separately and
 classified by the chapter name which can be run successfully in MATLAB The book can benefit researchers engineers and
 graduate students in the fields of PDE modeling and boundary vibration control of flexible structures **Intelligent
 Renewable Energy Systems** Gerasimos Rigatos,2016-08-06 Focused on renewable energy systems and the development of
 information and communication technologies ICTs for their integration in smart grids this book presents recent advances and
 methods that help to ensure that power generation from renewable sources remains stable that power losses are minimized
 and that the reliable functioning of these power generation units is maintained The book highlights key topics and
 technologies for renewable energy systems including the intelligent control of power generators power electronics that
 connect renewable power generation units to the grid and fault diagnosis for power generators and power electronics In
 particular the following topics are addressed Modeling and control of power generators PMSGs DFIGs Modeling and control
 of power electronics converters inverters Modeling and fault diagnosis of the transmission and distribution Grid and
 Modelling and control of distributed power generation units interconnected synchronous generators or photovoltaic units
 Because of the above coverage members of the wider engineering community will find that the nonlinear control and
 estimation methods presented provide essential insights into the functioning of renewable energy power systems while the
 academic community will find the book a valuable textbook for undergraduate or graduate courses on renewable energy
 systems **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 identifi
 cation of distributed parameter systems DPS and develop new spatio temporal models and their relevant identifi cation
 approaches In this book a systematic overview and classifi cation on the modeling of DPS is presented fi rst which includes
 model reduction parameter estimation and system identifi cation 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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