

Adaptive Robust Control Based on Moore-Penrose Generalized Inverse for Underactuated Mechanical Systems

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ABSTRACT To address the uncertainty existing in underactuated mechanical systems (UMSs) and their nonholonomic servo constraints, we propose a class of adaptive robust control based on the Moore-Penrose generalized inverse for UMSs in this paper. The uncertainty is considered as (possible fast) time-varying and bounded. However, the bound is unknown. To estimate the bound information, an adaptive law is designed, which combines leakage type and dead-zone type. This adaptive law can simultaneously regulate the control effort and computation speed. The proposed control can guarantee deterministic system performance, which is analyzed by using Lyapunov method. The effectiveness of proposed control is shown by an example of simplified two-wheeled self-balancing robot.

INDEX TERMS Underactuated mechanical systems, servo constraints, adaptive robust control, adaptive law, Moore-Penrose generalized inverse.

I. INTRODUCTION

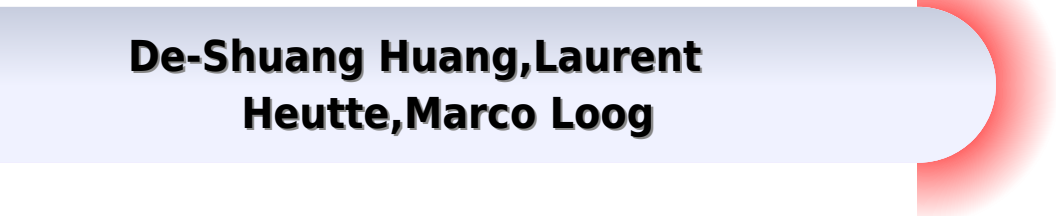
Underactuated manipulators [1], [2], UAVs [3], surface vessels [4], spacecraft [5], [6], underwater vehicles [7] and so on have generally become active fields for the past few years, because they are all underactuated mechanical systems (UMSs) that have the advantages of low number of actuators, weight, cost and energy consumption. However, complex internal dynamics, lack of feedback linearization and nonholonomic behavior also accompany UMSs, which increase the difficulty of designing controller for such systems. Even so, many brilliant work for such systems have been achieved in control field, such as sliding-mode [8]–[10], LQR [11], partial feedback linearization [12], [13], LMI [14], [15], H_∞ [16] and so on. However, most of the control methods mentioned above are difficult to deal with nonholonomic servo constraints [17].

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In 1992, Udwadia and Kalaba proposed a novel Udwadia-Kalaba equation [18] based on the Moore-Penrose generalized inverse, and through which can easily establish the motion equation of a mechanical system and solve the constraint forces without considering Lagrange multiplier. The Udwadia and Kalaba's work is a significant breakthrough in the field of dynamics. Based on the breakthrough, Udwadia proposed a novel servo control [19], which can easily handle nonholonomic servo constraints without relying on additional sophisticated mathematical tools in the control design of fully actuated mechanical systems. Furthermore, based on Udwadia's and Kalaba's work, in [20], Chen systematically proposed the concept of servo control for constrained mechanical systems and the design method of constraint forces. In [21], Liu et al. proposed a new servo control based on pioneer's work, which makes the advantages of Udwadia's control apply in controlling UMSs. However, Liu's work does not consider the uncertainty existing in UMSs. In real life, the uncertainty should be nonnegligible.

Adaptive Control Of Underactuated Mechanical Systems

**De-Shuang Huang, Laurent
Heutte, Marco Loog**



Adaptive Control Of Underactuated Mechanical Systems:

Adaptive Control Of Underactuated Mechanical Systems An-chyau Huang, Yung-feng Chen, Chen-yu Kai, 2015-01-29 In this book we collected recent results on the control of underactuated mechanical systems subject to internal uncertainties and external disturbances The strategy developed is so universal that it is not restricted to a specific system but a large class of underactuated systems Several benchmark systems are studied in this book including detailed literature review system dynamics derivation control problem formulation and simulation verification The control strategy developed in chapter 4 is able to stabilize all these benchmark systems with satisfactory performance regardless of the underactuated dynamics and various uncertainties The book is written as a text suitable for graduate students in the advanced course for the control of underactuated systems It also provides valuable tools for researchers and practicing engineers working on the control of underactuated mechanical systems

Adaptive and Fault-Tolerant Control of Underactuated Nonlinear Systems

Jiangshuai Huang, Yong-Duan Song, 2017-12-22 The purpose of the book is to provide an exposition of recently developed adaptive and fault tolerant control of underactuated nonlinear systems Underactuated systems are abundant in real life ranging from landing vehicles to surface ships and underwater vehicles to spacecrafts For the tracking and stabilization control of underactuated mechanical systems many methodologies have been proposed However a number of important issues deserve further investigation In response to these issues four important problems are solved in this book including control of underactuated nonlinear systems with input saturation output feedback control in the presence of parametric uncertainties fault tolerant control of underactuated ships with or without actuator redundancy and adaptive control of multiple underactuated nonlinear systems including formation control and flocking control of multiple underactuated systems

Motion Control of Underactuated Mechanical Systems Javier Moreno-Valenzuela, Carlos Aguilar-Avelar, 2017-07-11

This volume is the first to present a unified perspective on the control of underactuated mechanical systems Based on real time implementation of parameter identification this book provides a variety of algorithms for the Furuta pendulum and the inertia wheel pendulum which are two degrees of freedom mechanical systems Specifically this work addresses and solves the problem of motion control via trajectory tracking in one joint coordinate while another joint is regulated Besides discussions on extensions to higher degrees of freedom systems are given The book aimed at control engineers as well as graduate students ranges from the problem of parameter identification of the studied systems to the practical implementation of sophisticated motion control algorithms Offering real world solutions to manage the control of underactuated systems this book provides a concise tutorial on recent breakthroughs in the field original procedures to achieve bounding of the error trajectories convergence and gain tuning guidelines

Control of Underactuated Mechanical Systems Afef Hfaiedh, Ahmed Chemori, 2025-04-01 Control of Underactuated Mechanical Systems Stabilization and Limit Cycle Generation clearly explains stabilization and limit cycle generation in underactuated mechanical systems

UMS addressing control design challenges and demonstrating concepts through real time experiments The book begins with advancements in UMS introducing key concepts such as stabilization and limitcycle generation supported by literature examples It then focuses on the inertia wheel invertedpendulum presenting a detailed discussion The second part tackles stabilization offering variouscontrol solutions validated through numerical simulations and real time experiments The finalpart addresses stable limit cycle generation detailing three proposed control solutions and theirvalidation through different case studies This book is a valuable resource for PhD and Master students engineers researchers and educators It provides guidance in robotics and automatic control utilizing a simplified methodology forcontrolling underactuated mechanical systems Addresses stabilization and stable limit cycle generation in underactuated mechanical systemsamid perturbations Explores the design development and validation of robust control solutions Illustrates concepts through case studies Validates control solutions with numerical simulations and real time experiments

Analysis and Control of Underactuated Mechanical Systems Amal Choukchou-Braham, Brahim Cherki, Mohamed Djemaï, Krishna Busawon, 2013-11-18 This monograph provides readers with tools for the analysis and control of systems with fewer control inputs than degrees of freedom to be controlled i e underactuated systems The text deals with the consequences of a lack of a general theory that would allow methodical treatment of such systems and the ad hoc approach to control design that often results imposing a level of organization whenever the latter is lacking The authors take as their starting point the construction of a graphical characterization or control flow diagram reflecting the transmission of generalized forces through the degrees of freedom Underactuated systems are classified according to the three main structures by which this is found to happen chain tree and isolated vertex and control design procedures proposed The procedure is applied to several well known examples of underactuated systems acrobot pendubot Tora system ball and beam inertia wheel and robotic arm with elastic joint The text is illustrated with MATLABsup sup Simulink simulations that demonstrate the effectiveness of the methods detailed ppReaders interested in aircraft vehicle control or various forms of walking robot will be able to learn from iUnderactuated Mechanical Systems

Non-linear Control for Underactuated Mechanical Systems Isabelle Fantoni, Rogelio Lozano, 2012-12-06 This book deals with the application of modern control theory to some important underactuated mechanical systems from the inverted pendulum to the helicopter model It will help readers gain experience in the modelling of mechanical systems and familiarize with new control methods for non linear systems

Hierarchical Sliding Mode Control for Under-actuated Cranes Dianwei Qian, Jianqiang Yi, 2015-10-15 This book reports on the latest developments in sliding mode overhead crane control presenting novel research ideas and findings on sliding mode control SMC hierarchical SMC and compensator design based hierarchical sliding mode The results which were previously scattered across various journals and conference proceedings are now presented in a systematic and unified form The book will be of interest to researchers engineers and graduate students in control engineering and mechanical engineering who want to

learn the methods and applications of SMC **Control of Underactuated Manipulators** Jundong Wu, Pan Zhang, Qingxin Meng, Yawu Wang, 2023-05-13 This book investigates in detail cutting edge technologies of underactuated manipulator control which is a frontier topic in robotics that possesses great significance in energy conservation as well as fault tolerance for industrial applications It is also the crucial technology associated with systems in special environments including underwater or aerospace environments So far the topic of underactuated manipulator control has attracted engineers and scientists from various disciplines such as applied physics material automation and robotics Pursuing a holistic approach the book establishes a fundamental framework for this topic while emphasizing the importance of design and optimization in the control of underactuated manipulators Chapters of the book cover a wide variety of manipulator systems including vertical underactuated manipulator planar underactuated manipulator with first order nonholonomic constraint planar underactuated manipulator with second order nonholonomic constraint and flexible underactuated manipulator The book is intended for undergraduate and graduate students that are interested in underactuated manipulators researchers that investigate the design and optimization for controllers of underactuated manipulators and engineers working with underactuated systems

2011 International Conference in Electrics, Communication and Automatic Control Proceedings Ran Chen, 2011-11-25 2011 International Conference in Electrics Communication and Automatic Control Proceedings examines state of art and advances in Electrics Communication and Automatic Control This book presents developments in Power Conversion Signal and image processing Image video Signal Processing The conference brings together researchers engineers academic as well as industrial professionals from all over the world to promote the developments of Electrics Communication and Automatic Control **Advances and Applications in Sliding Mode Control systems** Ahmad Taher Azar, Quanmin Zhu, 2014-11-01 This book describes the advances and applications in Sliding mode control SMC which is widely used as a powerful method to tackle uncertain nonlinear systems The book is organized into 21 chapters which have been organised by the editors to reflect the various themes of sliding mode control The book provides the reader with a broad range of material from first principles up to the current state of the art in the area of SMC and observation presented in a clear matter of fact style As such it is appropriate for graduate students with a basic knowledge of classical control theory and some knowledge of state space methods and nonlinear systems The resulting design procedures are emphasized using Matlab Simulink software **Nonlinear and Adaptive Control** Alessandro Astolfi, 2006 This book summarizes the main results achieved in a four year European Project on nonlinear and adaptive control The project involves leading researchers from top notch institutions Imperial College London Prof A Astolfi Lund University Prof A Rantzer Supélec Paris Prof R Ortega University of Technology of Compiègne Prof R Lozano Grenoble Polytechnic Prof C Canudas de Wit University of Twente Prof A van der Schaft Politecnico di Milano Prof S Bittanti and Polytechnic University of Valencia Prof P Albertos The book also provides an introduction to theoretical advances in nonlinear and adaptive control and an overview of novel

applications of advanced control theory particularly topics on the control of partially known systems under actuated systems and bioreactors

Recent Advances in Electrical Engineering and Control Applications Mohammed Chadli, Sofiane Bououden, Ivan Zelinka, 2016-12-01 This book of proceedings includes papers presenting the state of art in electrical engineering and control theory as well as their applications The topics focus on classical as well as modern methods for modeling control identification and simulation of complex systems with applications in science and engineering The papers were selected from the hottest topic areas such as control and systems engineering renewable energy faults diagnosis faults tolerant control large scale systems fractional order systems unconventional algorithms in control engineering signals and communications The control and design of complex systems dynamics analysis and modeling of its behavior and structure is vitally important in engineering economics and in science generally science today Examples of such systems can be seen in the world around us and are a part of our everyday life Application of modern methods for control electronics signal processing and more can be found in our mobile phones car engines home devices like washing machines is as well as in such advanced devices as space probes and systems for communicating with them All these technologies are part of technological backbone of our civilization making further research and hi tech applications essential The rich variety of contributions appeals to a wide audience including researchers students and academics

Control in Bioprocessing Pablo A. López Pérez, Ricardo Aguilar López, Ricardo Femat, 2020-06-08 Closes the gap between bioscience and mathematics based process engineering This book presents the most commonly employed approaches in the control of bioprocesses It discusses the role that control theory plays in understanding the mechanisms of cellular and metabolic processes and presents key results in various fields such as dynamic modeling dynamic properties of bioprocess models software sensors designed for the online estimation of parameters and state variables and control and supervision of bioprocesses Control in Bioengineering and Bioprocessing Modeling Estimation and the Use of Sensors is divided into three sections Part I Mathematical preliminaries and overview of the control and monitoring of bioprocess provides a general overview of the control and monitoring of bioprocesses and introduces the mathematical framework necessary for the analysis and characterization of bioprocess dynamics Part II Observability and control concepts presents the observability concepts which form the basis of design online estimation algorithms software sensor for bioprocesses and reviews controllability of these concepts including automatic feedback control systems Part III Software sensors and observer based control schemes for bioprocesses features six application cases including dynamic behavior of 3 dimensional continuous bioreactors observability analysis applied to 2D and 3D bioreactors with inhibitory and non inhibitory models and regulation of a continuously stirred bioreactor via modeling error compensation Applicable across all areas of bioprocess engineering including food and beverages biofuels and renewable energy pharmaceuticals and nutraceuticals fermentation systems product separation technologies wastewater and solid waste treatment technology and bioremediation Provides a clear explanation of the mass balance based mathematical

modelling of bioprocesses and the main tools for its dynamic analysis Offers industry based applications on myco diesel for implementing quality of observability developing a virtual sensor based on the Just In Time Model to monitor biological control systems and virtual sensor design for state estimation in a photocatalytic bioreactor for hydrogen production Control in Bioengineering and Bioprocessing is intended as a foundational text for graduate level students in bioengineering as well as a reference text for researchers engineers and other practitioners interested in the field of estimation and control of bioprocesses

Distributed Adaptive Consensus Control of Uncertain Multi-Agent Systems Wei Wang,Jiang Long,Jiangshuai Huang,Changyun Wen,2024-08-15 Multi agent systems are special networked systems full of research interest and practical sense which are abundant in real life ranging from mobile robot networks intelligent transportation management to multiple spacecraft surveillance and monitoring Consensus control is one of the most typical and hot research issues for multi agent systems Distributed Adaptive Consensus Control of Uncertain Multi agent Systems provides innovative technologies to design and analyze distributed adaptive consensus for multi agent systems with model uncertainties Based on the basic graph theory and adaptive backstepping control this monograph Describes the state of the art on distributed adaptive control finite time consensus control and event triggered consensus control Studies distributed adaptive consensus under directed communication graph condition the methods with linearly parametric reference hierarchical decomposition and design of auxiliary filters Explores adaptive finite time consensus for uncertain nonlinear systems Considers distributed adaptive consensus with event triggered communication via state feedback and output feedback Investigates distributed adaptive formation control of nonholonomic mobile robots with experimental verification Provides distributed adaptive attitude synchronization control schemes for multiple spacecraft with event triggered communication Distributed Adaptive Consensus Control of Uncertain Multi agent Systems can help engineering students and professionals to efficiently learn distributed adaptive control design tool for handling uncertain multi agent systems with directed communication graph guaranteeing finite time convergence and saving communication resources

Advances in Applied Nonlinear Dynamics, Vibration, and Control - 2023 Xingjian Jing,Hu Ding,Jinchen Ji,Daniil Yurchenko,2024-02-10 This book provides readers with up to date advances in applied and interdisciplinary engineering science and technologies related to nonlinear dynamics vibration control robotics and their engineering applications developed in the most recent years All the contributed chapters come from active scholars in the area which cover advanced theory and methods innovative technologies benchmark experimental validations and engineering practices Readers would benefit from this state of the art collection of applied nonlinear dynamics in depth vibration engineering theory cutting edge control methods and technologies and definitely find stimulating ideas for their on going R D work This book is intended for graduate students research staff and scholars in academics and also provides useful hand up guidance for professionals and engineers in practical engineering missions

Advanced Intelligent Computing Theories and Applications - With Aspects of

Theoretical and Methodological Issues De-Shuang Huang, Laurent Heutte, Marco Loog, 2007-07-31 This volume in conjunction with the two volumes CICS 0002 and LNAI 4682 constitutes the refereed proceedings of the Third International Conference on Intelligent Computing held in Qingdao China in August 2007 The 139 full papers published here were carefully reviewed and selected from among 2 875 submissions Collectively these papers represent some of the most important findings and insights into the field of intelligent computing *Advances in Information and Communication Technology* Phung Trung Nghia, Vu Duc Thai, Nguyen Thanh Thuy, Le Hoang Son, Van-Nam Huynh, 2024-01-03 This book contains four keynote abstracts and 83 best peer reviewed papers selected from the 179 submissions at the 2nd International Conference on Advances in ICT ICTA 2023 which share research results and practical applications in ICT research and education Technological changes and digital transformation that have taken place over the past decade have had significant impacts on all economic and social sectors Information and Communication Technology ICT in general and artificial intelligence AI in particular have driven socio economic growth The topics cover all ICT related areas and their contributions to socio economic development focusing on the most advanced technologies such as AI Researchers and practitioners in academia and industry use the books as a valuable reference for their research activities teaching learning and advancing current technologies The Conference is hosted by Thai Nguyen University of Information and Communication Technology

Block Backstepping Design of Nonlinear State Feedback Control Law for Underactuated Mechanical Systems Shubhobrata Rudra, Ranjit Kumar Barai, Madhubanti Maitra, 2016-09-08 This book presents a novel generalized approach to the design of nonlinear state feedback control laws for a large class of underactuated mechanical systems based on application of the block backstepping method The control law proposed here is robust against the effects of model uncertainty in dynamic and steady state performance and addresses the issue of asymptotic stabilization for the class of underactuated mechanical systems An underactuated system is defined as one for which the dimension of space spanned by the configuration vector is greater than that of the space spanned by the control variables Control problems concerning underactuated systems currently represent an active field of research due to their broad range of applications in robotics aerospace and marine contexts The book derives a generalized theory of block backstepping control design for underactuated mechanical systems and examines several case studies that cover interesting examples of underactuated mechanical systems The mathematical derivations are described using well known notations and simple algebra without the need for any special previous background in higher mathematics The chapters are lucidly described in a systematic manner starting with control system preliminaries and moving on to a generalized description of the block backstepping method before turning to several case studies Simulation and experimental results are also provided to aid in reader comprehension

Practical Issues of Intelligent Innovations Vassil Sgurev, Vladimir Jotsov, Janusz Kacprzyk, 2018-07-05 This book presents recent advances in the field of intelligent systems Composed of fourteen selected chapters it covers a wide range of research

that varies from applications in industrial data science to those in applied science Today the word INNOVATION is more and more connected with the words INTELLIGENT and SECURITY as such the book discusses the theory and applications of hot topics such as big data education applications of robots with different levels of autonomy knowledge based modeling and control of complex dynamical systems sign based synthesis of behavior security issues with intelligent systems innovative intelligent control design neuromorphic computation data driven classification intelligent modeling and measurement innovations multisensor data association personal education assistants a modern production architecture study of peer review and scientometrics intelligent research on bug report data and clustering non Gaussian data The broad and varied research discussed represents the mainstream of contemporary intelligent innovations that are slowly but surely changing the world

Nonlinear Control and Filtering Using Differential Flatness Approaches Gerasimos G. Rigatos, 2015-06-05 This monograph presents recent advances in differential flatness theory and analyzes its use for nonlinear control and estimation It shows how differential flatness theory can provide solutions to complicated control problems such as those appearing in highly nonlinear multivariable systems and distributed parameter systems Furthermore it shows that differential flatness theory makes it possible to perform filtering and state estimation for a wide class of nonlinear dynamical systems and provides several descriptive test cases The book focuses on the design of nonlinear adaptive controllers and nonlinear filters using exact linearization based on differential flatness theory The adaptive controllers obtained can be applied to a wide class of nonlinear systems with unknown dynamics and assure reliable functioning of the control loop under uncertainty and varying operating conditions The filters obtained outperform other nonlinear filters in terms of accuracy of estimation and computation speed The book presents a series of application examples to confirm the efficiency of the proposed nonlinear filtering and adaptive control schemes for various electromechanical systems These include industrial robots mobile robots and autonomous vehicles electric power generation electric motors and actuators power electronics internal combustion engines distributed parameter systems and communication systems Differential Flatness Approaches to Nonlinear Control and Filtering will be a useful reference for academic researchers studying advanced problems in nonlinear control and nonlinear dynamics and for engineers working on control applications in electromechanical systems

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Adaptive Control Of Underactuated Mechanical Systems Introduction

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