

# Finite-Time Convergent Observer Design and Adaptive Control of a Nonlinear Boiler System

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**Abstract**—In this paper, based on recently developed finite-time convergent observer designs with time-varying coefficients, an observer is first designed to yield the explicit values of unknown parameters of a nonlinear boiler system. Then an adaptive controller is designed to regulate the states of the boiler system. Compared to existing results, the contribution of the paper is two-fold: (i) the new approach is able to handle the case when all parameters are unknown; (ii) faster convergence rates can be achieved to identify the unknown parameters and regulate the boiler system. Computer simulations are conducted to show the effectiveness of the proposed adaptive control schemes.

## I. INTRODUCTION

In the nonlinear control community, the finite-time stabilization problem has attracted increasing attention since the 1990s. As presently known, finite-time convergence means that the states of system converge to their equilibrium in a finite time. As pointed out in [3], finite-time convergence implies that the dynamic system does not satisfy Lipschitz continuity. So continuous but non-smooth control via state or dynamic output feedback can provide a finite-time convergence rate for the equilibrium of the system. These closed-loop systems are of interest not only because of faster convergence rates around the equilibrium, but also because they can perform better disturbance rejection capabilities as shown from papers [1], [2], [3].

Due to the aforementioned benefits, abundant theoretical results and various design tools for finite-time control have been developed in recent years. First, for double integrator systems, the work [2] proposes a homogeneous state feedback control method which has further inspired many works in this direction. For high order systems, because the non-Lipschitz feature of the control system, the well-known backstepping (also called adding a linear integrator) strategy is not applicable. A new tool called adding a power integrator technique was first presented in [11], [4] and later extended in [8], [5], [6], etc. More significantly, the development of a homogeneous approach plays an important role for the finite-time convergent controller design. In [7], a generalized homogeneous controller which expands many former works, including those in the area of finite-time stabilization, is proposed.

When compared to the various finite-time stabilization results using state feedback, the results of finite-time output feedback control are relatively fewer. Some interesting results about finite-time stabilization using output feedback were proposed based on homogeneous systems theory. In particular, second dimensional case was studied in [12], [6]. For the problem of designing an  $n$ -dimensional finite-time convergent observer, some design methods based on homogeneous systems theory can be found in [14], [15], [13], [16] and the references therein.

It is of practical value to use finite-time convergent observers since finite-time convergence enables us to obtain the exact values of the unmeasurable states after a finite time. This is in sharp contrast to the conventional linear based observers whose estimated states converge to the real states asymptotically (in infinite time). Also, finite-time convergent observers have been applied to some practical systems. For example, the work performed in [9] applies the finite-time convergent observers to a planar vertical take-off and landing aircraft(PVTOL), and a finite-time convergent output feedback controller is designed for a novel quad-rotor mini-aircraft in [10].

However, these continuous finite-time convergent observers mentioned above are only applicable to those systems with constant coefficients, and thus pose a limitation for their applications in practice where many nonlinear systems contain time-varying coefficients. For instance, time-varying functions are needed to be addressed in the nonlinear drum boiler model [18]. This paper intends to fill the gap in research and results surrounding finite-time convergent observers for nonlinear systems with time-varying coefficients. In this paper, a finite-time convergent observer for a class of nonlinear systems with time-varying constants and bounded states is first developed. Then a drum-boiler system will be considered as an application of the finite-time convergent observer.

The main objective of the boiler-turbine system control is to meet the load demand of electric power while maintaining the pressure and water level in the drum within tolerances. As is already known in real practices, some or even all of the parameters for a boiler turbine model are subject to change. Firstly, it is difficult to construct an exact model for the boiler system due to its complexities. Moreover, even if an exact model is acquired at a certain operating point, its parameters will still vary while the operating

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# Control And Observer Design For Nonlinear Finite A

**Sukhan Lee, Il Hong Suh**



## **Control And Observer Design For Nonlinear Finite A:**

**Control and Observer Design for Nonlinear Finite and Infinite Dimensional Systems** Thomas Meurer, Knut Graichen, Ernst-Dieter Gilles, 2005-09-19 This volume presents a well balanced combination of state of the art theoretical results in the field of nonlinear controller and observer design combined with industrial applications stemming from mechatronics electrical bio chemical engineering and fluid dynamics The unique combination of results of finite as well as infinite dimensional systems makes this book a remarkable contribution addressing postgraduates researchers and engineers both at universities and in industry The contributions to this book were presented at the Symposium on Nonlinear Control and Observer Design From Theory to Applications SYNCOD held September 15 16 2005 at the University of Stuttgart Germany The conference and this book are dedicated to the 65th birthday of Prof Dr Ing Dr h c Michael Zeitz to honor his life long research and contributions on the fields of nonlinear control and observer design *Control and Observer Design for Nonlinear Finite and Infinite Dimensional Systems* Thomas Meurer, Knut Graichen, Ernst-Dieter Gilles, 2009-09-02 This volume presents a well balanced combination of state of the art theoretical results in the field of nonlinear controller and observer design combined with industrial applications stemming from mechatronics electrical bio chemical engineering and fluid dynamics The unique combination of results of finite as well as infinite dimensional systems makes this book a remarkable contribution addressing postgraduates researchers and engineers both at universities and in industry The contributions to this book were presented at the Symposium on Nonlinear Control and Observer Design From Theory to Applications SYNCOD held September 15 16 2005 at the University of Stuttgart Germany The conference and this book are dedicated to the 65th birthday of Prof Dr Ing Dr h c Michael Zeitz to honor his life long research and contributions on the fields of nonlinear control and observer design *Observer Design for Nonlinear Dynamical Systems* Driss Boutat, Gang Zheng, 2021-07-02 This book presents a differential geometric method for designing nonlinear observers for multiple types of nonlinear systems including single and multiple outputs fully and partially observable systems and regular and singular dynamical systems It is an exposition of achievements in nonlinear observer normal forms The book begins by discussing linear systems introducing the concept of observability and observer design and then explains the difficulty of those problems for nonlinear systems After providing foundational information on the differential geometric method the text shows how to use the method to address observer design problems It presents methods for a variety of systems The authors employ worked examples to illustrate the ideas presented Observer Design for Nonlinear Dynamical Systems will be of interest to researchers graduate students and industrial professionals working with control of mechanical and dynamical systems *Observer Design for Nonlinear Systems with Reduced Observability Properties* Alejandro Vargas, 2003

**Fundamentals of Stochastic Filtering** Alan Bain, Dan Crisan, 2008-10-08 Many aspects of phenomena critical to our lives can not be measured directly Fortunately models of these phenomena together with more limited observations frequently

allow us to make reasonable inferences about the state of the systems that affect us. The process of using partial observations and a stochastic model to make inferences about an evolving system is known as stochastic filtering. The objective of this text is to assist anyone who would like to become familiar with the theory of stochastic filtering, whether graduate student or more experienced scientist. The majority of the fundamental results of the subject are presented using modern methods, making them readily available for reference. The book may also be of interest to practitioners of stochastic filtering who wish to gain a better understanding of the underlying theory. Stochastic filtering in continuous time relies heavily on measure theory, stochastic processes, and stochastic calculus. While knowledge of basic measure theory and probability is assumed, the text is largely self-contained in that the majority of the results needed are stated in two appendices. This should make it easy for the book to be used as a graduate teaching text. With this in mind, each chapter contains a number of exercises with solutions detailed at the end of the chapter.

**16th European Symposium on Computer Aided Process Engineering and 9th International Symposium on Process Systems Engineering** W. Marquardt, C. Pantelides, 2006. This proceedings book brings together the leading innovations and achievements by leading professionals. It acts as a forum for engineers, scientists, researchers, managers, and students from academia and industry to present and discuss progress being made in research and application of computer aided process engineering.

*Visual Servoing via Advanced Numerical Methods* Graziano Chesi, Koichi Hashimoto, 2010-03-10. Robots able to imitate human beings have been at the core of stories of science fiction as well as dreams of inventors for a long time. Among the various skills that Mother Nature has provided us with and that often go forgotten, the ability of sight is certainly one of the most important. Perhaps inspired by tales of Isaac Asimov, comics, and cartoons, and surely helped by the progress of electronics in recent decades, researchers have progressively made the dream of creating robots able to move and operate by exploiting artificial vision a concrete reality. Technically speaking, we would say that these robots position themselves and their end effectors by using the view provided by some artificial eyes as feedback information. Indeed, the artificial eyes are visual sensors such as cameras that have the function to acquire an image of the environment. Such an image describes if and how the robot is moving toward the goal and hence constitutes feedback information. This procedure is known in robotics with the term visual servoing, and it is nothing else than an imitation of the intrinsic mechanism that allows human beings to realize daily tasks such as reaching the door of the house or grasping a cup of coffee.

**21st European Symposium on Computer Aided Process Engineering**, 2011-06-10. The European Symposium on Computer Aided Process Engineering (ESCAPE) series presents the latest innovations and achievements of leading professionals from the industrial and academic communities. The ESCAPE series serves as a forum for engineers, scientists, researchers, managers, and students to present and discuss progress being made in the area of computer aided process engineering. European industries large and small are bringing innovations into our lives, whether in the form of new technologies to address environmental problems, new products to make our homes more comfortable and energy

efficient or new therapies to improve the health and well being of European citizens Moreover the European Industry needs to undertake research and technological initiatives in response to humanity s Grand Challenges described in the declaration of Lund namely Global Warming Tightening Supplies of Energy Water and Food Ageing Societies Public Health Pandemics and Security Thus the Technical Theme of ESCAPE 21 will be Process Systems Approaches for Addressing Grand Challenges in Energy Environment Health Bioprocessing Nanotechnologies

*An Approach to Multi-agent Systems as a Generalized Multi-synchronization Problem* Rafael Martínez-Guerra, Juan Pablo Flores-Flores, 2023-03-09 This book addresses the problem of multi agent systems considering that it can be interpreted as a generalized multi synchronization problem From manufacturing tasks through encryption and communication algorithms to high precision experiments the simultaneous cooperation between multiple systems or agents is essential to successfully carrying out different modern activities both in academy and industry For example the coordination of multiple assembler robots in manufacturing lines These agents need to synchronize The first two chapters of the book describe the synchronization of dynamical systems paying special attention to the synchronization of non identical systems Following the third chapter presents an interesting application of the synchronization phenomenon for state estimation Subsequently the authors fully address the multi agent problem interpreted as multi synchronization The final chapters introduce the reader to a more complex problem the synchronization of systems governed by partial differential equations both of integer and fractional order The book aimed at graduates postgraduate students and researchers closely related to the area of automatic control Previous knowledge of linear algebra classical and fractional calculus is requested as well as some fundamental notions of graph theory

*Handbook of Hybrid Systems Control* Jan Lunze, Françoise Lamnabhi-Lagarigue, 2009-10-15 Setting out core theory and reviewing a range of new methods theoretical problems and applications this handbook shows how hybrid dynamical systems can be modelled and understood Sixty expert authors involved in the recent research activities and industrial application studies provide practical insights on topics ranging from the theoretical investigations over computer aided design to applications in energy management and the process industry Structured into three parts the book opens with a thorough introduction to hybrid systems theory illustrating new dynamical phenomena through numerous examples Part II then provides a survey of key tools and tool integration activities Finally Part III is dedicated to applications implementation issues and system integration considering different domains such as industrial control automotive systems and digital networks Three running examples are referred to throughout the book together with numerous illustrations helping both researchers and industry professionals to understand complex theory recognise problems and find appropriate solutions

**Modal Array Signal Processing: Principles and Applications of Acoustic Wavefield Decomposition** Heinz Teutsch, 2007-01-10 This book deals with the problem of detecting and localizing multiple simultaneously active wideband acoustic sources by applying the notion of wavefield decomposition using circular and spherical microphone arrays A rigorous derivation of modal array signal processing

algorithms for unambiguous source detection and localization as well as performance evaluations by means of measurements using an actual real time capable implementation are discussed

### **Applications of Nonlinear Control** Meral

Altınay,2012-06-13 A trend of investigation of Nonlinear Control Systems has been present over the last few decades As a result the methods for its analysis and design have improved rapidly This book includes nonlinear design topics such as Feedback Linearization Lyapunov Based Control Adaptive Control Optimal Control and Robust Control All chapters discuss different applications that are basically independent of each other The book will provide the reader with information on modern control techniques and results which cover a very wide application area Each chapter attempts to demonstrate how one would apply these techniques to real world systems through both simulations and experimental settings

### **Stability and Convergence of Mechanical Systems with Unilateral Constraints** Remco I. Leine,Nathan van de Wouw,2007-12-29

Stability of motion is a central theme in the dynamics of mechanical systems While the stability theory for systems with bilateral constraints is a well established field this monograph represents a systematic study of mechanical systems with unilateral constraints such as unilateral contact impact and friction Such unilateral constraints give rise to non smooth dynamical models for which stability theory is developed in this work The book starts with the treatise of the mathematical background on non smooth analysis measure and integration theory and an introduction to the field of non smooth dynamical systems The unilateral constraints are modelled in the framework of set valued force laws developed in the field of non smooth mechanics The embedding of these constitutive models in the dynamics of mechanical systems gives rises to dynamical models with impulsive phenomena This book uses the mathematical framework of measure differential inclusions to formalise such models The book proceeds with the presentation of stability results for measure differential inclusions These stability results are then applied to nonlinear mechanical systems with unilateral constraints The book closes with the study of the convergence property for a class of measure differential inclusions a stability property for systems with time varying inputs which is shown to be highly instrumental in the context of the control of mechanical systems with unilateral constraints While the book presents a profound stability theory for mechanical systems with unilateral constraints it also has a tutorial value on the modelling of such systems in the framework of measure differential inclusions The work will be of interest to engineers scientists and students working in the field of non smooth mechanics and dynamics

### **Complex Systems: Spanning Control and Computational Cybernetics: Foundations** Peng Shi,Jovan Stefanovski,Janusz Kacprzyk,2022-08-24

This book dedicated to Professor Georgi M Dimirovski on his anniversary contains new research directions challenges and many relevant applications related to many aspects within the broadly perceived areas of systems and control including signal analysis and intelligent systems The project comprises two volumes with papers written by well known and very active researchers and practitioners The first volume is focused on more foundational aspects related to general issues in systems science and mathematical systems various problems in control and automation and the use of computational and artificial intelligence in

the context of systems modeling and control The second volume is concerned with a presentation of relevant applications notably in robotics computer networks telecommunication fault detection diagnosis as well as in biology and medicine and economic financial and social systems too

*Numerical Simulation of Turbulent Flows and Noise Generation* Christophe Brun, Daniel Juvé, Michael Manhart, Claus-Dieter Munz, 2009-03-07 Large Eddy Simulation LES is a high fidelity approach to the numerical simulation of turbulent flows Recent developments have shown LES to be able to predict aerodynamic noise generation and propagation as well as the turbulent flow by means of either a hybrid or a direct approach This book is based on the results of two French German research groups working on LES simulations in complex geometries and noise generation in turbulent flows The results provide insights into modern prediction approaches for turbulent flows and noise generation mechanisms as well as their use for novel noise reduction concepts

Active Flow Control Rudibert King, 2007-08-29 The dramatically increasing requirements of mobility through road rail and airborne transport systems in the future necessitate non evolutionary improvements of transportation systems Without severe implications concerning the environment or restrictions concerning the performance these requirements will only be met by a concerted action of many disciplines It is believed that with ACTIVE FLOW CONTROL a key technology exists to supply an important block in the mosaic to be laid in the pursuit of best and sustainable solutions Manipulation of uid ows is highly advantageous in many cases Aerodynamic or uid ows around or inside bodies imposed drag lift and moments on the body remove or supply energy by convection Flow induced noise may be produced by the interaction of a body with the surrounding air Moreover the interaction with the body changes the state of the ow drastically A neatly aligned laminar ow around a wing of an aircraft giving enough lift can become highly irregular and separated from the surface with the result of a loss of lift For cooling of gines of transport and other systems highly irregular turbulent uid ows across the components are needed to guarantee a large heat transfer In future engines of airplanes complying for example with the EU Vision 2020 an increased heat transfer on the other hand has to be avoided by all means in some parts of the engine Turbine stages may be exposed here to extremely hot gases needed for high efficiency which would destroy the blades In this application more laminar ow regimes would be advantageous yielding a poorer heat transfer Their irregular ow in a combustor g

Recent Progress in Robotics: Viable Robotic Service to Human Sukhan Lee, Il Hong Suh, 2008-01-14 This volume is an edition of the papers selected from the 13 International Conference on Advanced Robotics ICAR 2007 held in Jeju Korea August 22-25 2007 with the theme Viable Robotics Service to Human It is intended to deliver readers the most recent technical progress in robotics in particular toward the advancement of robotic service to human To ensure its quality this volume took only 28 papers out of the 214 papers accepted for publication for ICAR 2007 The selection was based mainly on the technical merit but also took into consideration whether the subject represents a theme of current interest For the final inclusion authors of the selected papers were requested for another round of revision and expansion In this volume we organize the 28 contributions into

three chapters Chapter 1 covers Novel Mechanisms Chapter 2 deals with perception guided navigation and manipulation and Chapter 3 addresses human robot interaction and intelligence Chapters 1 2 and 3 consist of 7 13 and 8 contributions respectively For the sake of clarity Chapter 2 is divided further into two parts with Part 1 for Perception Guided Navigation and Part 2 for Perception Guided Manipulation Chapter 3 is also divided into two parts with Part 1 for Human Robot Interaction and Part 2 for Intelligence For the convenience of readers a chapter summary is introduced as an overview in the beginning of each chapter The chapter summaries were prepared by Dr Munsang Kim for Chapter 1 Prof

**Model-Based Reinforcement Learning** Milad Farsi, Jun Liu, 2022-12-28 Model Based Reinforcement Learning Explore a comprehensive and practical approach to reinforcement learning Reinforcement learning is an essential paradigm of machine learning wherein an intelligent agent performs actions that ensure optimal behavior from devices While this paradigm of machine learning has gained tremendous success and popularity in recent years previous scholarship has focused either on theory optimal control and dynamic programming or on algorithms most of which are simulation based Model Based Reinforcement Learning provides a model based framework to bridge these two aspects thereby creating a holistic treatment of the topic of model based online learning control In doing so the authors seek to develop a model based framework for data driven control that bridges the topics of systems identification from data model based reinforcement learning and optimal control as well as the applications of each This new technique for assessing classical results will allow for a more efficient reinforcement learning system At its heart this book is focused on providing an end to end framework from design to application of a more tractable model based reinforcement learning technique Model Based Reinforcement Learning readers will also find A useful textbook to use in graduate courses on data driven and learning based control that emphasizes modeling and control of dynamical systems from data Detailed comparisons of the impact of different techniques such as basic linear quadratic controller learning based model predictive control model free reinforcement learning and structured online learning Applications and case studies on ground vehicles with nonholonomic dynamics and another on quadrator helicopters An online Python based toolbox that accompanies the contents covered in the book as well as the necessary code and data Model Based Reinforcement Learning is a useful reference for senior undergraduate students graduate students research assistants professors process control engineers and roboticists

**Applications of Time Delay Systems** John Chiasson, Jean Jacques Loiseau, 2007-02-08 This book provides an update of the latest research in control of time delay systems and applications by world leading experts It will appeal to engineers researchers and students in Control

**Intelligent Decision Technologies** Junzo Watada, Gloria Phillips-Wren, Lakhmi C. Jain, Robert J. Howlett, 2011-11-19 Intelligent Decision Technologies IDT seeks an interchange of research on intelligent systems and intelligent technologies which enhance or improve decision making in industry government and academia The focus is interdisciplinary in nature and includes research on all aspects of intelligent decision technologies from fundamental development to the applied system This volume



represents leading research from the Third KES International Symposium on Intelligent Decision Technologies KES IDT 11 hosted and organized by the University of Piraeus Greece in conjunction with KES International The symposium was concerned with theory design development implementation testing and evaluation of intelligent decision systems Topics include decision making theory intelligent agents fuzzy logic multi agent systems Bayesian networks optimization artificial neural networks genetic algorithms expert systems decision support systems geographic information systems case based reasoning time series knowledge management systems rough sets spatial decision analysis and multi criteria decision analysis These technologies have the potential to revolutionize decision making in many areas of management healthcare international business finance accounting marketing military applications ecommerce network management crisis response building design information retrieval and disaster recovery for a better future The symposium was concerned with theory design development implementation testing and evaluation of intelligent decision systems Topics include decision making theory intelligent agents fuzzy logic multi agent systems Bayesian networks optimization artificial neural networks genetic algorithms expert systems decision support systems geographic information systems case based reasoning time series knowledge management systems rough sets spatial decision analysis and multi criteria decision analysis These technologies have the potential to revolutionize decision making in many areas of management healthcare international business finance accounting marketing military applications ecommerce network management crisis response building design information retrieval and disaster recovery for a better future

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