

Development of a Nonlinear Model Predictive Control-Based Nonlinear Three-Mode Controller for a Nonlinear System

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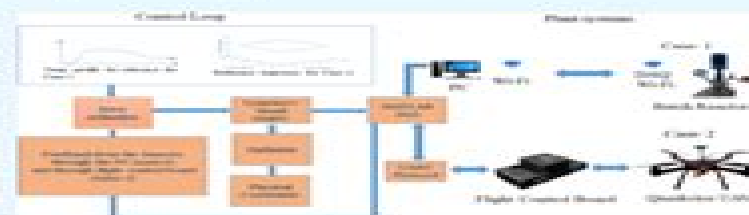
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ABSTRACT: This paper presents the novelty on a nonlinear proportional integral derivative (NPID) controller developed from the gain values obtained using the Lyapunov-based nonlinear model predictive controller (LyNMPC). The tuning parameters of the proposed controller are taken from the dynamics of the nonlinear system, and these parameters are dynamic with their value varying according to the error in the system. In this article, the authors have considered two highly nonlinear systems, namely, batch polymerization reactor and quadrotor unmanned aerial vehicle systems. The nonlinear mathematical modeling of the batch reactor as well as the quadrotor system considered from the past literature of authors. The acrylamide polymerization reaction under consideration is an exothermic reaction, thereby making the temperature profile tracking and control a challenging task. The primary aim of this article is to develop the NPID controller based on the LyNMPC algorithm and to validate the NPID on a batch reactor bench-scale plant and on an hardware-in-the-loop platform for the quadrotor hardware. A comparative study of trajectory tracking and control capabilities of LyNMPC on derived non-linear models of the batch reactor and quadrotor system is presented. The system mathematical models are obtained with the help of the first-principle energy balance equation for the batch reactor and with the nonlinear dynamics of the quadrotor which is derived based on Newton–Euler formulations. With LyNMPC, the stability of the nonlinear systems can be improved because the error sensitivity is considered in the cost function.



INTRODUCTION

The batch reactors are highly nonlinear and non-steady systems with the primary objective to maintain the reactor temperature with respect to the temperature profile. If the reactor temperature is not maintained with respect to optimal trajectory formed, the reactor may face thermal runaway issues,^{1–5} which in-turn is due to the sudden conversion of a polymer into a monomer. Hence the optimal control of coolant flow-rate should be used as a manipulated variable with constant heater supply in this experimental study. The highly nonlinear batch reactor stability needs to be ensured while tracking the trajectory to avoid the byproduct formation and thermal runaway. Similarly, unmanned aerial vehicles (UAVs) or drones have been under a rapidly growing field of research. The applications of UAVs have been growing day-by-day and can be categorized as scientific, commercial, or military applications. Micro-UAVs or micro-aerial vehicles (MAVs) are classified as miniature UAVs of different build configurations, which vary from the tiny insect sized aircrafts to the small quadrotors and the fixed wing aircrafts. The MAVs due to their smaller size range are more useful in the remote missions, show similarities with their

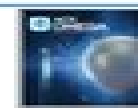
UAV counterparts in various characteristics but differ in terms of the magnitude of the aerodynamic forces experienced, and are more susceptible to external forces due to their smaller size and lower inertia. Hence, the problem of tracking and control of the MAVs is a much more challenging task to achieve.

Model predictive control (MPC) is a sophisticated control method which has various applications in the chemical and petroleum industries, where the physical hard constraints can be handled effectively. The MPC is a finite-boundary iterative optimization technique very useful in situ technique where the plant requirements vary with time. The MPC algorithm determines the control variables from the values obtained previously. Linear MPCs are the most common form of control used in the applications of MPC with the feedback

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Nonlinear Process Control

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Nonlinear Process Control M. Chidambaram, 1995 This Book Is Intended For Researchers In Process Control And Applied Mathematics It Can Also Serve As A Textbook For Graduate Students Interested In Nonlinear Control Theory After Discussing The Basic Design Method Of Model Reference Nonlinear Controller Mrnc The Book Deals With The Incorporation Of Explicit Integral And Derivative Actions In The Control Law Extension Of The Method To Systems With Relative Order Two And Higher Is Provided The Design Of Series Cascade Mrnc Systems And Parallel Cascade Mrnc Systems Are Given Extensions Of Mrnc For Systems With Significant Measurement Dynamics Or Actuator Dynamics Are Made The Design Method Of Mrnc For Systems With Delay In Measurement Or In Actuator Is Provided Simulation Studies On Several Nonlinear Processes Prove The Effectiveness Of The Mrnc

Nonlinear Process Control: Peter L. Lee, 2012-12-06 It is a valuable contribution to the task of filling the theory and practice gap that exists in Process Control The volume editor has drawn together a number of industrial case studies where Generic Model Control has been successfully applied Each case study is documented and described in detail Nonlinear Process Control will be of particular interest to industrial practitioners It provides a tutorial introduction to Generic Model Control and assists them in applying modern control methods to their processes

Nonlinear Process Control Michael A. Henson, Dale E. Seborg, 1997 Nonlinear Process Control assembles the latest theoretical and practical research on design analysis and application of nonlinear process control strategies It presents detailed coverage of all three major elements of nonlinear process control identification controller design and state estimation Nonlinear Process Control reflects the contributions of eleven leading researchers in the field It is an ideal textbook for graduate courses in process control as well as a concise up to date reference for control engineers

Nonlinear Model Based Process Control Rıdvan Berber, Costas Kravaris, 1998 The increasingly competitive environment within which modern industry has to work means that processes have to be operated over a wider range of conditions in order to meet constantly changing performance targets Add to this the fact that many industrial operations are nonlinear and the need for on line control algorithms for nonlinear processes becomes clear Major progress has been booked in constrained model based control and important issues of nonlinear process control have been solved This text surveys the state of the art in nonlinear model based control technology by writers who have actually created the scientific profile A broad range of issues are covered in depth from traditional nonlinear approaches to nonlinear model predictive control from nonlinear process identification and state estimation to control integrated design Advances in the control of inverse response and unstable processes are presented Comparisons with linear control are given and case studies are used for illustration

Nonlinear Model Based Process Control R. Berber, Costas Kravaris, 2012-12-06 The ASI on Nonlinear Model Based Process Control August 10 20 1997 Antalya Turkey convened as a continuation of a previous ASI which was held in August 1994 in Antalya on Methods of Model Based Process Control in a more general context In 1994 the contributions and

discussions convincingly showed that industrial process control would increasingly rely on nonlinear model based control systems. Therefore the idea for organizing this ASI was motivated by the success of the first one, the enthusiasm expressed by the scientific community for continuing contact and the growing incentive for on line control algorithms for nonlinear processes. This is due to tighter constraints and constantly changing performance objectives that now force the processes to be operated over a wider range of conditions compared to the past and the fact that many of industrial operations are nonlinear in nature. The ASI intended to review in depth and in a global way the state of the art in nonlinear model based control. The list of lecturers consisted of 12 eminent scientists leading the principal developments in the area as well as industrial specialists experienced in the application of these techniques. Selected out of a large number of applications there was a high quality active audience composed of 59 students from 20 countries. Including family members accompanying the participants the group formed a large body of 92 persons. Out of the 71 participants 11 were from industry.

Instrument Engineers' Handbook, Volume Two Bela G. Liptak, 2018-10-08 The latest update to Bela Liptak's acclaimed bible of instrument engineering is now available. Retaining the format that made the previous editions bestsellers in their own right, the fourth edition of *Process Control and Optimization* continues the tradition of providing quick and easy access to highly practical information. The authors are practicing engineers, not theoretical people from academia, and their advice has been repeatedly tested in real life applications. Expanded coverage includes descriptions of overseas manufacturers' products and concepts, model based optimization in control theory, new major inventions and innovations in control valves, and a full chapter devoted to safety. With more than 2000 graphs, figures, and tables, this all inclusive encyclopedic volume replaces an entire library with one authoritative reference. The fourth edition brings the content of the previous editions completely up to date, incorporates the developments of the last decade, and broadens the horizons of the work from an American to a global perspective. Bela G. Liptak speaks on Post Oil Energy Technology on the AT T Tech Channel.

Process Control Jie Bao, Peter L. Lee, 2007-06-14 Passivity and associated stability conditions form one of the cornerstones in control theory and have begun to be applied in process control. In this book, passivity based developments in all areas of control theory are addressed systematically for the first time. The emphasis is placed on real results that add insight. Case studies illustrate applications in all the main chapters. MATLAB routines and a library of functions that implement the methods developed in the book can be downloaded from springer.com.

Process Control Béla G. Lipták, 2013-10-02 *Instrument Engineers Handbook Third Edition Process Control* provides information pertinent to control hardware including transmitters, controllers, control valves, displays, and computer systems. This book presents the control theory and shows how the unit processes of distillation and chemical reaction should be controlled. Organized into eight chapters, this edition begins with an overview of the method needed for the state of the art practice of process control. This text then examines the relative merits of digital and analog displays and computers. Other chapters consider the basic industrial annunciators and other alarm

systems which consist of multiple individual alarm points that are connected to a trouble contact a logic module and a visual indicator This book discusses as well the data loggers available for process control applications The final chapter deals with the various pump control systems the features and designs of variable speed drives and the metering pumps This book is a valuable resource for engineers

Process Control Jean-Pierre Corriou,2013-03-09 A wide range of identification and control methods applicable to processes are accompanied by typical comparable examples encouraging you to make comparisons The initial classical approach to continuous control by transfer functions will be of enormous benefit whether you are a student beginning in control or an engineer in industry who up until now has only had a land contact with control The more advanced material on discrete control and the state space control as well as nonlinear control and observers requires minimal previous knowledge enabling you to make better use of performing techniques Progressively it introduces concepts of increasing difficulty allowing a less brutal tuition of theories and control methods For each topic the theories techniques and algorithms are presented in detail with numerous references The consideration of the same problems by different approaches will provoke a deep understanding It includes all necessary explanations for your complete understanding of the subject and examples that you can reproduce to master the different techniques Broad coverage creates an important synthesis on the majority of aspects of control giving you a complete view of control theory and possible applications within the field Different levels of reading are possible opening this powerful source of information to students engineers academics and researchers alike

Introduction to Process Control Jose A. Romagnoli,Ahmet Palazoglu,2020-07-14 Introduction to Process Control Third Edition continues to provide a bridge between traditional and modern views of process control by blending conventional topics with a broader perspective of integrated process operation control and information systems Updated and expanded throughout this third edition addresses issues highly relevant to today s teaching of process control Discusses smart manufacturing new data preprocessing techniques and machine learning and artificial intelligence concepts that are part of current smart manufacturing decisions Includes extensive references to guide the reader to the resources needed to solve modeling classification and monitoring problems Introduces the link between process optimization and process control optimizing control including the effect of disturbances on the optimal plant operation the concepts of steady state and dynamic back off as ways to quantify the economic benefits of control and how to determine an optimal transition policy during a planned production change Incorporates an introduction to the modern architectures of industrial computer control systems with real case studies and applications to pilot scale operations Analyzes the expanded role of process control in modern manufacturing including model centric technologies and integrated control systems Integrates data processing reconciliation and intelligent monitoring in the overall control system architecture Drawing on the authors combined 60 years of teaching experiences this classroom tested text is designed for chemical engineering students but is also suitable for industrial practitioners who need to understand key concepts of process control

and how to implement them The text offers a comprehensive pedagogical approach to reinforce learning and presents a concept first followed by an example allowing students to grasp theoretical concepts in a practical manner and uses the same problem in each chapter culminating in a complete control design strategy A vast number of exercises throughout ensure readers are supported in their learning and comprehension Downloadable MATLAB toolboxes for process control education as well as the main simulation examples from the book offer a user friendly software environment for interactively studying the examples in the text These can be downloaded from the publisher s website Solutions manual is available for qualifying professors from the publisher

Analysis and Control of Nonlinear Process Systems Katalin M. Hangos,Jozsef Bokor,Gabor Szederkenyi,2014-01-15 Nonlinear Control Systems Design 1995 A.J. Krener,D.Q. Mayne,2016-01-22 The series of IFAC Symposia on Nonlinear Control Systems provides the ideal forum for leading researchers and practitioners who work in the field to discuss and evaluate the latest research and developments This publication contains the papers presented at the 3rd IFAC Symposium in the series which was held in Tahoe City California USA

Control of Nonlinear and Hybrid Process Systems Panagiotis D. Christofides,Nael El-Farra,2005-10-04 This monograph provides insight and fundamental understanding into the feedback control of nonlinear and hybrid process systems It presents state of the art methods for the synthesis of nonlinear feedback controllers for nonlinear and hybrid systems with uncertainty constraints and time delays with numerous applications especially to chemical processes It covers both state feedback and output feedback including state estimator design controller designs Control of Nonlinear and Hybrid Process Systems includes numerous comments and remarks providing insight and fundamental understanding into the feedback control of nonlinear and hybrid systems as well as applications that demonstrate the implementation and effectiveness of the presented control methods The book includes many detailed examples which can be easily modified by a control engineer to be tailored to a specific application This book is useful for researchers in control systems theory graduate students pursuing their degree in control systems and control engineers

Microcomputer Application in Process Control E. Adali,F. Tunali,2014-06-28 This symposium brings together the research from different disciplines of process control and discusses the problems encountered in the application of automation systems The papers in this volume analyze the results of theoretical research and how far applications have been developed new design methodologies and technologies to give a comprehensive overview of the state of the art of this fast developing science

Advances in Process Control with Real Applications Ch. Venkateswarlu,2025-06-18 *Advances in Process Control with Real Applications* presents various advanced controllers including the formulation design and implementation of various advanced control strategies for a wide variety of processes These strategies include generalized predictive control with and without constraints linear and nonlinear model predictive control dynamic matrix control nonlinear control such as generic model control globally linearizing control and nonlinear internal model control optimal and optimizing control inferential control intelligent control based on fuzzy reasoning and

neural networks and controllers based on stochastic and evolutionary optimization This book will be highly beneficial to students researchers and industry professionals working in process design process monitoring process systems engineering process operations and control and related areas Describes various advanced controllers for the control of complex nonlinear processes Provides the fundamentals algorithms approaches control strategies and implementation procedures systematically Highlights the significance and importance of advanced process control with many real applications

Fault-Tolerant Process Control Prashant Mhaskar, Jinfeng Liu, Panagiotis D. Christofides, 2012-11-27 Fault Tolerant Process Control focuses on the development of general yet practical methods for the design of advanced fault tolerant control systems these ensure an efficient fault detection and a timely response to enhance fault recovery prevent faults from propagating or developing into total failures and reduce the risk of safety hazards To this end methods are presented for the design of advanced fault tolerant control systems for chemical processes which explicitly deal with actuator controller failures and sensor faults and data losses Specifically the book puts forward A framework for detection isolation and diagnosis of actuator and sensor faults for nonlinear systems Controller reconfiguration and safe parking based fault handling methodologies Integrated data and model based fault detection and isolation and fault tolerant control methods Methods for handling sensor faults and data losses and Methods for monitoring the performance of low level PID loops The methodologies proposed employ nonlinear systems analysis Lyapunov techniques optimization statistical methods and hybrid systems theory and are predicated upon the idea of integrating fault detection local feedback control and supervisory control The applicability and performance of the methods are demonstrated through a number of chemical process examples Fault Tolerant Process Control is a valuable resource for academic researchers industrial practitioners as well as graduate students pursuing research in this area

Process Control in Practice Tore Hägglund, 2023-08-21 This book covers the most important topics that people working as process control engineers and plant operators will encounter It focuses on PID control explains when to use P PI PD or PID control as well as PID tuning and includes difficult to control process nonlinearities such as valve stiction or sensor problems The book also explains advanced control strategies that are necessary when single loop control gives insufficient results The key features of the text in front of you are This book is a result of teaching the material to industrial practitioners over three decades and four previous editions in Swedish each of which was a refinement of the previous one A key contribution of this book is the careful selection of what is required when you are at a plant and have to make sense of what you see The book is written in such a way that it does not assume mathematical knowledge above the compulsory school level Process control sits between control engineering and process or chemical engineering and often there is a distinct gap between the two By explaining both the fundamentals of control and the processes the book is written to appeal to control engineers and process engineers alike The book includes exercises and solutions and thus lends itself for teaching in the classroom

Introduction to Process Control, Second Edition Jose A.

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Digital Computer Applications to Process Control M. Paul,2016-11-04 Considers the application of modern control engineering on digital computers with a view to improving productivity and product quality easing supervision of industrial processes and reducing energy consumption and pollution The topics covered may be divided into two main subject areas 1 applications of digital control in the chemical and oil industries in water turbines energy and power systems robotics and manufacturing cement metallurgical processes traffic control heating and cooling 2 systems theoretical aspects of digital control adaptive systems control aspects multivariable systems optimization and reliability modelling and identification real time software and languages distributed systems and data networks Contains 84 papers

Multivariable System Identification For Process Control Y. Zhu,2001-10-08 Systems and control theory has experienced significant development in the past few decades New techniques have emerged which hold enormous potential for industrial applications and which have therefore also attracted much interest from academic researchers However the impact of these developments on the process industries has been limited The purpose of Multivariable System Identification

for Process Control is to bridge the gap between theory and application and to provide industrial solutions based on sound scientific theory to process identification problems The book is organized in a reader friendly way starting with the simplest methods and then gradually introducing more complex techniques Thus the reader is offered clear physical insight without recourse to large amounts of mathematics Each method is covered in a single chapter or section and experimental design is explained before any identification algorithms are discussed The many simulation examples and industrial case studies demonstrate the power and efficiency of process identification helping to make the theory more applicable Matlab™ M files designed to help the reader to learn identification in a computing environment are included

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