

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

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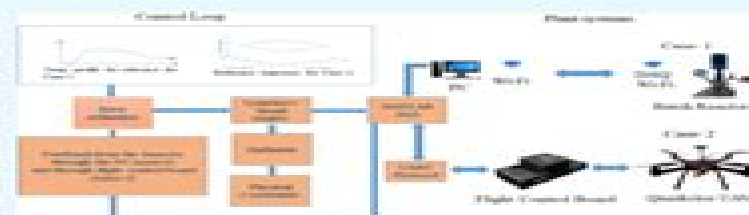
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**ABSTRACT:** This paper presents the novelty on a nonlinear proportional integral derivative (NPID) controller developed from the gain values obtained using the Lyapunov-based nonlinear model predictive controller (LyNMPC). The tuning parameters of 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 a 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,<sup>1–3</sup> 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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Szederkenyi**



## **Nonlinear Process Control:**

**Nonlinear Model Based Process Control** Ridvan 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 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 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* 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 *Process Control* Jean-Pierre Corriou, 2004-03-18 This reference book can be read at different levels making it a powerful source of information It presents most of the aspects of control that can help anyone to have a synthetic view of control theory and possible applications especially concerning process engineering **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

**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

**Analysis and Control of Nonlinear Process Systems** Katalin M. Hantos, Jozsef Bokor, Gabor Szederkenyi, 2014-01-15

**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

*Nonlinear Process Control* Frank Allgöwer, 1997

**Advanced Control of Chemical Processes (ADCHEM'91)** K. Najim, E. Dufour, 2014-05-23 This volume contains 40 papers which describe the recent developments in advanced control of chemical processes and related industries The topics of adaptive control model based control and neural networks are covered by 3 survey papers New adaptive statistical model based control and artificial intelligence techniques and their applications are detailed in several papers The problem of implementation of control algorithms on a digital computer is also considered

*Model Based Process Control* International Federation of Automatic Control, 1989-03-30 Presented at this workshop were mathematical models upon which process control is based and the practical applications of this method of control within industry case studies include examples from the paper and pulp industry materials industry and the chemical industry among others From these presentations emerged a need for further research and development into process control

Containing 19 papers these Proceedings will be a valuable reference work for all those involved in the designing of continuous production processes for industry and for the end user involved in the practical application of process control within their manufacturing process

**Nonlinear Model-Based Control** R. Russell Rhinehart, 2024-04-01 Nonlinear Model Based Control Using First Principles Models in Process Control First principles models engineering models are used in industry for process design troubleshooting training online analysis and supervisory optimization The author's vision is to use them for control Why They effectively handle nonlinearity nonstationary behavior

and interacting variables with just one tuning coefficient per controlled variable CV Using optimization the controller can handle constraints and shape the manipulated variables to achieve desired controlled variable trajectories Using first principles models for control can also enhance the operational staff's understanding of the process support auxiliary process management and keep the mathematics at the engineers comfort level In addition unifying all models across diverse process management operations ensures continuity and compatibility The book explains four control techniques using first principles models that have been credibly demonstrated for industrial practice generic model control process model based control predictive functional control and horizon predictive control It illustrates their applications and discusses the pros and cons of each To provide a better understanding of first principles models the book includes examples of setting up functions for controllers and discusses inherent properties such as ease of tuning the handling of nonlinearity and interaction feedforward constraints and the range of operation

*Nonlinear Model-based Process Control* Rashid M. Ansari, Moses O. Tade, 2011-12-21 The series Advances in Industrial Control aims to report and encourage technology transfer in control engineering The rapid development of control technology has an impact on all areas of the control discipline New theory new controllers actuators sensors new industrial processes computer methods new applications new philosophies new challenges Much of this development work resides in industrial reports feasibility study papers and the reports of advanced collaborative projects The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination The last decade has seen considerable interest in reviving the fortunes of non linear control In contrast to the approaches of the 60S 70S and 80S a very pragmatic agenda for non linear control is being pursued using the model based predictive control paradigm This text by R Ansari and M Tade gives an excellent synthesis of this new direction Two strengths emphasized by the text are i four applications found in refinery processes are used to give the text a firm practical continuity ii a non linear model based control architecture is used to give the method a coherent theoretical framework

Digital Control and Monitoring Methods for Nonlinear Processes Nguyen Huynh, 2006 Abstract The chemical engineering literature is dominated by physical and bio chemical processes that exhibit complex nonlinear behavior and as a consequence the associated requirements of their analysis optimization control and monitoring pose considerable challenges in the face of emerging competitive pressures on the chemical petrochemical and pharmaceutical industries The above operational requirements are now increasingly imposed on processes that exhibit inherently nonlinear behavior over a wide range of operating conditions rendering the employment of linear process control and monitoring methods rather inadequate At the same time increased research efforts are now concentrated on the development of new process control and supervisory systems that could be digitally implemented with the aid of powerful computer software codes In particular it is widely recognized that the important objective of process performance reliability can be met through a comprehensive framework for process control and monitoring From I a process safety point of view the

more reliable the process control and monitoring scheme employed and the earlier the detection of an operationally hazardous problem the greater the intervening power of the process engineering team to correct it and restore operational order II a product quality point of view the earlier detection of an operational problem might prevent the unnecessary production of o spec products and subsequently minimize cost The present work proposes a new methodological perspective and a novel set of systematic analytical tools aiming at the synthesis and tuning of well performing digital controllers and the development of monitoring algorithms for nonlinear processes In particular the main thematic and research axis traced are I The systematic integrated synthesis and tuning of advanced model based digital controllers using techniques conceptually inspired by Zubov s advanced stability theory II The rigorous quantitative characterization and monitoring of the asymptotic behavior of complex nonlinear processes using the notion of invariant manifolds and functional equations theory III The systematic design of nonlinear state observer based process monitoring systems to accurately reconstruct unmeasurable process variables in the presence of time scale multiplicity IV The design of robust nonlinear digital observers for chemical reaction systems in the presence of model uncertainty

**Non-linear Predictive Control** Basil Kouvaritakis,Mark Cannon,2001-10-26 The advantage of model predictive control is that it can take systematic account of constraints thereby allowing processes to operate at the limits of achievable performance Engineers in academia industry and government from the US and Europe explain how the linear version can be adapted and applied to the nonlinear conditions that characterize the dynamics of most real manufacturing plants They survey theoretical and practical trends describe some specific theories and demonstrate their practical application derive strategies that provide appropriate assurance of closed loop stability and discuss practical implementation Annotation copyrighted by Book News Inc Portland OR

**Robustness Properties of Nonlinear Process Control and Implications for the Design and Control of a Packed Bed Reactor** Francis J. Doyle,1991 Chemical Process Control-V Jeffrey C. Kantor,Carlos E. García,Brice Carnahan,1997 Chemical Process Control by Inversion of a Nonlinear Process Model Lance Arthur Edwards,1985 Transition Control Techniques in Nonlinear Process Control Leyla Özkan,2002 The control strategy is further modified by the addition of a contractive constraint to guarantee stability The use of piecewise linear models and a switching criterion has added a hybrid characteristic to the control structure Therefore a recent approach in analysis of hybrid systems called multiple Lyapunov functions is utilized in the stability analysis of the closed loop system

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