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PAPERS

Modelling, analysis and control design of hybrid dynamical systems

Dominik Vošček, Anna Jadlovská, Dominik Grigľák*

This paper introduces a methodology for one of the challenges regarding cyber-physical systems, ie modelling and control design them as hybrid systems. The proposed methodology comprises modules with specific steps to accomplish the tasks. Specifically, the paper aims to utilize hybrid systems framework onto the chosen hydraulic hybrid system with complex dynamics to showcase different aspects of hybrid systems. The mathematical model was derived using hybrid automata framework and then transformed into the linear form either using Jacobi matrices or using linear approximations without Jacobi matrices. After that the system was validated and analysed and the control design utilizing piecewise linear-quadratic regulator optimal control was proposed. Furthermore, parameters of control algorithm were tuned using particle swarm optimization algorithm. The whole logic, system dynamics and constraints are implemented within MATLAB/Simulink simulation environment using s-functions. The proposed methodology can be implemented on the various types of cyber-physical systems as far as they can be described as hybrid systems.

K e y w o r d s: cyber-physical system, hydraulic hybrid system, methodology, particle swarm optimization, piecewise affine system, piecewise LQR optimal control

1 Introduction

Cyber-physical systems (CPS), defined as an integration of physical processes with computation platforms, are an integral part of the phenomenon Industry 4.0. One of their complexity challenges stated in [1, 2] can be formulated as to model and control CPS within hybrid systems framework [3].

This paper focusses specifically on this challenge of CPS from modelling up to the control design as hybrid systems (HS) [4, 5]. The most convenient hybrid systems framework for such a task is hybrid automata (HA) which naturally deals with a continuous and discrete dynamics of hybrid systems [6]. However, such a mathematical representation is not appropriate for analysis and control design of CPS. For these tasks, different but equivalent mathematical representations were introduced, eg piecewise affine (PWA) systems [7].

There have been proposed several approaches to unify the procedure to model, analyse and design control algorithms for hybrid systems. Within mentioned procedures belong one published in [8], however, this approach does not utilize analysis of the system in the open loop and during control synthesis no metaheuristic algorithms to tune control parameters were used. Another approach, published in [9], utilizes supervisory control of hybrid systems but omits the analysis part. Methodology utilizing modelling and diagnosis of hybrid systems was proposed in [10].

Goal of this article is to propose and introduce the unified methodology for the whole process from modelling up to the control design and therefore cover all the steps to ensure proper design and analysis of CPS as a hybrid system. This process was partially introduced in [2, 11] and will be completed with regards to other research challenges. The methodology consists of several steps, namely determination of HA elements such as possible discrete modes and transitions between them, followed by assigning continuous dynamics to these modes. At this point it is possible to simulate and analyse the hybrid system.

After validation of the system, design control utilizing appropriate control algorithms can be implemented onto the hybrid system. Between the most used control algorithms for hybrid systems belong model predictive control based on multiparametric optimization [12] and piecewise optimal linear quadratic (LQR) optimal control [13]. These methods were chosen as representatives of control algorithms for hybrid systems. However, there are many others such as semi-Markov mode switching for linear parameter-varying systems [14] or supervisory control [15].

While designing control law, a metaheuristic method for tuning control law parameters can be utilized. Between these metaheuristic methods belong eg particle swarm optimization (PSO) [16], artificial bee colony [17], ant colony optimization [18] or grey wolf optimization approach [19]. We have chosen PSO algorithm as a representative example for tuning control algorithm parameters. This algorithm was then applied onto all controllable discrete modes of the HS.

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Modelling Analysis And Design Of Hybrid Systems

Gorazd Karer,Igor Škrjanc

Modelling Analysis And Design Of Hybrid Systems:

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design algorithms are provided in a MATLAB toolbox that enable both academic examples and industrial application studies to be repeated and evaluated taking into account practical application and implementation problems The text makes nonlinear control theory accessible to readers having only a background in linear systems and concentrates on real applications of nonlinear control It covers different ways of modelling nonlinear systems including state space polynomial based linear parameter varying state dependent and hybrid design techniques for nonlinear optimal control including generalised minimum variance model predictive control quadratic Gaussian factorised and H design methods design philosophies that are suitable for aerospace automotive marine process control energy systems robotics servo systems and manufacturing steps in design procedures that are illustrated in design studies to define cost functions and cope with problems such as disturbance rejection uncertainties and integral wind up and baseline non optimal control techniques such as nonlinear Smith predictors feedback linearization sliding mode control and nonlinear PID Nonlinear Industrial Control Systems is valuable to engineers in industry dealing with actual nonlinear systems It provides students with a comprehensive range of techniques and examples for solving real nonlinear control design problems **Mathematical Modelling, Optimization, Analytic and Numerical Solutions** Pammy Manchanda,René Pierre Lozi,Abul Hasan Siddiqi,2020-02-04 This book discusses a variety of topics related to industrial and applied mathematics focusing on wavelet theory sampling theorems inverse problems and their applications partial differential equations as a model of real world problems computational linguistics mathematical models and methods for meteorology earth systems environmental and medical science and the oil industry It features papers presented at the International Conference in Conjunction with 14th Biennial Conference of ISIAM held at Guru Nanak Dev University Amritsar India on 2 4 February 2018 The conference has emerged as an influential forum bringing together prominent academic scientists experts from industry and researchers The topics discussed include Schrodinger operators quantum kinetic equations and their application extensions of fractional integral transforms electrical impedance tomography diffuse optical tomography Galerkin method by using wavelets a Cauchy problem associated with Korteweg de Vries equation and entropy solution for scalar conservation laws This book motivates and inspires young researchers in the fields of industrial and applied mathematics *Proceedings of the 2018 International Symposium on Experimental Robotics* Jing Xiao,Torsten Kröger,Oussama Khatib,2020-01-22 In addition to the contributions presented at the 2018 International Symposium on Experimental Robotics ISER 2018 this book features summaries of the discussions that were held during the event in Buenos Aires Argentina These summaries authored by leading researchers and session organizers offer important insights on the issues that drove the symposium debates Readers will find cutting edge experimental research results from a range of robotics domains such as medical robotics unmanned aerial vehicles mobile robot navigation mapping and localization field robotics robot learning robotic manipulation human robot interaction and design and prototyping In this unique collection of the latest experimental robotics work the common thread is the

experimental testing and validation of new ideas and methodologies The International Symposium on Experimental Robotics is a series of bi annual symposia sponsored by the International Foundation of Robotics Research whose goal is to provide a dedicated forum for experimental robotics research In recent years robotics has broadened its scientific scope deepened its methodologies and expanded its applications However the significance of experiments remains at the heart of the discipline The ISER gatherings are an essential venue where scientists can meet and have in depth discussions on robotics based on this central tenet **Graph Transformations and Model-Driven Engineering** Gregor Engels,Claus Lewerentz,Wilhelm Schäfer,Andy Schürr,Bernhard Westfechtel,2010-11-08 This festschrift volume published in honor of Manfred Nagl on the occasion of his 65th birthday contains 30 refereed contributions that cover graph transformations software architectures and reengineering embedded systems engineering and more *Computational Mathematics, Modelling and Algorithms* J. C. Misra,2003 This comprehensive volume introduces educational units dealing with important topics in Mathematics Modelling and Algorithms Key Features Illustrative examples and exercises Comprehensive bibliography Discrete-Event Modeling and Simulation Gabriel A. Wainer,Pieter J. Mosterman,2018-09-03 Collecting the work of the foremost scientists in the field Discrete Event Modeling and Simulation Theory and Applications presents the state of the art in modeling discrete event systems using the discrete event system specification DEVS approach It introduces the latest advances recent extensions of formal techniques and real world examples of various applications The book covers many topics that pertain to several layers of the modeling and simulation architecture It discusses DEVS model development support and the interaction of DEVS with other methodologies It describes different forms of simulation supported by DEVS the use of real time DEVS simulation the relationship between DEVS and graph transformation the influence of DEVS variants on simulation performance and interoperability and composability with emphasis on DEVS standardization The text also examines extensions to DEVS new formalisms and abstractions of DEVS models as well as the theory and analysis behind real world system identification and control To support the generation and search of optimal models of a system a framework is developed based on the system entity structure and its transformation to DEVS simulation models In addition the book explores numerous interesting examples that illustrate the use of DEVS to build successful applications including optical network on chip construction building design process control workflow systems and environmental models A one stop resource on advances in DEVS theory applications and methodology this volume offers a sampling of the best research in the area a broad picture of the DEVS landscape and trend setting applications enabled by the DEVS approach It provides the basis for future research discoveries and encourages the development of new applications **Advanced Topics in Control Systems Theory** Antonio Loría,Françoise Lamnabhi-Lagarrigue,Elena Panteley,2006-02-09 This book includes selected contributions by lecturers at the third annual Formation d Automatique de Paris It provides a well integrated synthesis of the latest thinking in nonlinear optimal control observer design stability analysis and structural properties of linear systems without the need for

an exhaustive literature review The internationally known contributors to this volume represent many of the most reputable control centers in Europe Predictive Approaches to Control of Complex Systems Gorazd Karer,Igor Škrjanc,2012-09-20 A predictive control algorithm uses a model of the controlled system to predict the system behavior for various input scenarios and determines the most appropriate inputs accordingly Predictive controllers are suitable for a wide range of systems therefore their advantages are especially evident when dealing with relatively complex systems such as nonlinear constrained hybrid multivariate systems etc However designing a predictive control strategy for a complex system is generally a difficult task because all relevant dynamical phenomena have to be considered Establishing a suitable model of the system is an essential part of predictive control design Classic modeling and identification approaches based on linear systems theory are generally inappropriate for complex systems hence models that are able to appropriately consider complex dynamical properties have to be employed in a predictive control algorithm This book first introduces some modeling frameworks which can encompass the most frequently encountered complex dynamical phenomena and are practically applicable in the proposed predictive control approaches Furthermore unsupervised learning methods that can be used for complex system identification are treated Finally several useful predictive control algorithms for complex systems are proposed and their particular advantages and drawbacks are discussed The presented modeling identification and control approaches are complemented by illustrative examples The book is aimed towards researches and postgraduate students interested in modeling identification and control as well as towards control engineers needing practically usable advanced control methods for complex systems Discrete-time Sliding Mode Control B. Bandyopadhyay,S. Janardhanan,2005-10-17 Sliding mode control is a simple and yet robust control technique where the system states are made to confine to a selected subset With the increasing use of computers and discrete time samplers in controller implementation in the recent past discrete time systems and computer based control have become important topics This monograph presents an output feedback sliding mode control philosophy which can be applied to almost all controllable and observable systems while at the same time being simple enough as not to tax the computer too much It is shown that the solution can be found in the synergy of the multirate output sampling concept and the concept of discrete time sliding mode control *Theory of the Non-linear Analog Phase Locked Loop* Nikolaos I. Margaris,2004-05-18 This book develops for the first time a complete and connected nonlinear theory for the analog Phase Locked Loop PLL which clarifies the obscure points of its complex non linear behaviour The book suggests new non linear models for the PLL components and applies the averaging method to analyse PLL The book presents the physical interpretation of the PLL operation locates the difficulties presented by its operation and suggests solutions to overcome these problems Finally it provides closed form expressions for all the important measures of the PLL and proposes new design criteria **Logic, Computation and Rigorous Methods** Alexander Raschke,Elvinia Riccobene,Klaus-Dieter Schewe,2021-06-04 This Festschrift was published in honor of Egon B rger on the occasion of his

75th birthday It acknowledges Prof B rger s inspiration as a scientist author mentor and community organizer Dedicated to a pioneer in the fields of logic and computer science Egon B rger s research interests are unusual in scope from programming languages to hardware architectures software architectures control systems workflow and interaction patterns business processes web applications and concurrent systems The 18 invited contributions in this volume are by leading researchers in the areas of software engineering programming languages business information systems and computer science logic

Mathematical Problems from Applied Logic II Dov Gabbay,Sergei Goncharov,Michael Zakharyaschev,2007-07-28 Mathematical Problems from Applied Logic II presents chapters from selected world renowned logicians Important topics of logic are discussed from the point of view of their further development in light of requirements arising from their successful application in areas such as Computer Science and AI language Fields covered include logic of provability applications of computability theory to biology psychology physics chemistry economics and other basic sciences computability theory and computable models logic and space time geometry hybrid systems logic and region based theory of space Contributors include Sergei Artemov USA John Case USA Sergei Goncharov Russia Judit X Madar sz Istv n N meti and Gergely Sz kely Hungary Anil Nerode USA and Dimiter Vakarelov Bulgaria Innovations in Electrical and Electronics Engineering H. S. Saini,T. Srinivas,D. M. Vinod Kumar,K. S. Chandragupta Mauryan,2020-03-23 This book is a collection of selected research papers presented at the International Conference on Innovations in Electrical and Electronics Engineering ICIEEE 2019 which was organized by the Guru Nanak Institutions Ibrahimpatnam Hyderabad Telangana India on July 26 27 2019 The book highlights the latest developments in electrical and electronics engineering especially in the areas of power systems power electronics control systems electrical machinery and renewable energy The solutions discussed here will encourage and inspire researchers industry professionals and policymakers to put these methods into practice **Simulation-based Optimization of Energy Efficiency in Production** Anna Carina Römer,2021-02-11 The importance of the energy and commodity markets has steadily increased since the first oil crisis The sustained use of energy and other resources has become a basic requirement for a company to competitively perform on the market The modeling analysis and assessment of dynamic production processes is often performed using simulation software While existing approaches mainly focus on the consideration of resource consumption variables based on metrologically collected data on operating states the aim of this work is to depict the energy consumption of production plants through the utilization of a continuous simulation approach in combination with a discrete approach for the modeling of material flows and supporting logistic processes The complex interactions between the material flow and the energy usage in production can thus be simulated closer to reality especially the depiction of energy consumption peaks becomes possible An essential step towards reducing energy consumption in production is the optimization of the energy use of non value adding production phases *Reconfigurable Control of Nonlinear Dynamical Systems* Jan H. Richter,2011-01-16 This research monograph summarizes solutions to reconfigurable

fault tolerant control problems for nonlinear dynamical systems that are based on the fault hiding principle It emphasizes but is not limited to complete actuator and sensor failures In the first part the monograph starts with a broad introduction of the control reconfiguration problems and objectives as well as summaries and explanations of solutions for linear dynamical systems The solution is always a reconfiguration block which consists of linear virtual actuators in the case of actuator faults and linear virtual sensors in the case of sensor faults The main advantage of the fault hiding concept is the reusability of the nominal controller which remains in the loop as an active system while the virtual actuator and sensor adapt the control input and the measured output to the fault scenario The second and third parts extend virtual actuators and virtual sensors towards the classes of Hammerstein Wiener systems and piecewise affine systems The main analyses concern stability recovery setpoint tracking recovery and performance recovery as reconfiguration objectives The fourth part concludes the monograph with descriptions of practical implementations and case studies The book is primarily intended for active researchers and practicing engineers in the field of fault tolerant control Due to many running examples it is also suitable for interested graduate students

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