New advances in H∞ control and filtering for nonlinear systems

Editorial: New Advances in H_∞ Control and Filtering for Nonlinear Systems

Editors:
Dr. Michael Basin[1] *and Dr. Peng Shi*[2]

Welcome to the Special Issue on New Advances in H_∞ Control and Filtering for Nonlinear Systems. While the H_∞ control and filtering theory for linear systems was well established since the early 1990s, the H_∞ methods for nonlinear systems are still being actively developed varying from rigorous substantiation of nonlinear H_∞ approach to technical design of advanced H_∞ algorithms for special classes of nonlinear systems. Advanced technologies are promoting new applications of the H_∞ control and filtering in such areas as network-based communication, adaptive control, signal processing, and fault detection. Novel techniques, such as H_2/H_∞ approach, stochastic H-infinity, H_∞ methods for time-delay systems, LMI-based algorithms, energy-to-peak optimization, risk-sensitive methods, and others, have successfully complemented the classical H_∞ theory.

The main objective of this Special Issue is to summarize recent advances in H_∞ control and filtering for nonlinear systems, including time-delay, hybrid, and stochastic systems. The published papers provide new ideas and approaches, clearly indicating the advances made in problem statements, methodologies, or applications with respect to the existing results. The Special Issue also includes papers focusing on advanced and non-traditional methods and presenting considerable novelties in theoretical background or experimental setup. Some papers present applications to newly emerging fields such as network-based control and estimation.

The past several years have witnessed a growing interest in developing powerful techniques of H_∞ control and filtering for nonlinear systems, such as H_2/H_∞ approach, energy-to-peak optimization, LMI-based methods, H_∞ stochastic control and filtering, sliding mode algorithms, and others. This Special Issue provides our readers with a focused set of peer-reviewed articles to reflect recent advances in the state-of-the-art design techniques as well as other important aspects of the field. The Special Issue also serves as a forum for researchers to exchange their latest findings, as well as stimulate further research and development in this still fast-growing area.

The Special Issue contains seventeen papers that address various important issues in the design of H_∞ control and filtering algorithms for nonlinear systems. Accordingly, the accepted papers are divided into two large groups, presenting nonlinear H_∞ filtering and control algorithms, respectively. The first group, "New Advances in H_∞ Filtering for Nonlinear Systems," opens with the paper "Central suboptimal H_∞ Controller Design for Linear Time-Varying Systems with Unknown Parameters," by M. Basin, P. Soto, and D. Calderon-Alvarez. This paper presents the central finite-dimensional H_∞ controller for linear time-varying systems with unknown parameters, that is suboptimal for a given threshold γ with respect to a modified Bolza-Meyer quadratic criterion including the attenuation control term with the opposite sign. In contrast to the existing results, the paper reduces

[1]Department of Physical and Mathematical Sciences, Autonomous University of Nuevo Leon, Apdo postal 144-F, C.P. 66450, San Nicolas de los Garza, Nuevo Leon, Mexico, Phone: + 52 81 83294030, Fax: + 52 81 83522954, E-mail: mbasin@fcfm.uanl.mx

[2]Department of Computing and Mathematical Sciences, Faculty of Advanced Technology, University of Glamorgan, Pontypridd, CF37 1DL, United Kingdom, Phone: (+44 1443) 482147, Fax: (+44 1443) 482711, Email: pshi@glam.ac.uk. He is also with School of Engineering and Science, Victoria University, Melbourne, Vic 8001, Australia, and School of Mathematics and Statistics, University of South Australia, Mawson Lakes, 5095, Australia.

the original H_∞ controller problem to a corresponding H_2 controller problem. The paper yields the central suboptimal H_∞ controller for linear systems with unknown parameters in a closed finite-dimensional form, based on the corresponding H_2 controller. Numerical simulations are conducted to verify the performance of the designed central suboptimal controller for uncertain linear systems with unknown parameters against the conventional central suboptimal H_∞ controller for linear systems with exactly known parameter values.

The second paper, ”State Exact Reconstruction for Switched Linear Systems via a Super-Twisting Algorithm,” by F. Bejarano and L. Fridman, is concerned with the problem of state reconstruction synthesis for switched linear systems. Based only on the continuous output information, an observer is proposed ensuring the reconstruction of the entire state (continuous and discrete) in finite time. For the observer design an exact sliding mode differentiator is used, which allows the finite time convergence of the observer trajectories to the actual trajectories. The design scheme includes both cases: zero control input and nonzero control input. Simulations illustrate the effectiveness of the proposed observer.

The third paper, ”Continuous and Discrete State Reconstruction for Nonlinear Switched Systems via High-Order Sliding Mode Observers,” by J. Davila, A. Pisano, and E. Usai, studies a class of nonlinear switched systems and proposes a finite-time converging state observer. The observer strategy, based on the high-order sliding mode approach, enables one to reconstruct both, continuous and discrete, states of the switched system, based on output measurements and the knowledge of the set of possible system dynamics. All the ”operating modes” of the switched system are required to satisfy certain observability-like and boundedness restrictions. The observer provides a finite-time converging estimate and, after a switching on the active mode, it features an arbitrarily fast transient to recover the correct (continuous and discrete) state estimates. A numerical example illustrates the performance of the proposed observer.

The next paper, ”Periodic Motion Planning and Nonlinear H_∞ Tracking Control of a 3-DOF Underactuated Helicopter,” by I. Mesa-Sanchez, L. Aguilar, A. Shiriaev, L. Freidovich, and Y. Orlov, focuses on nonlinear H_∞ synthesis to solve the tracking control problem for a 3-DOF helicopter prototype. Planning of periodic motions under a virtual constraints approach is considered prior to the controller design. A local H_∞ controller is designed by changing the parameters of the differential Riccati equations that appear while solving the corresponding H_∞ control problem for the linearized system. Stabilizability and detectability properties of the control system are thus ensured by the existence of the proper solutions of the unperturbed differential Riccati equations, and hence the proposed synthesis procedure obviates extra verification work of these properties. Due to the nature of the approach, the resulting controller additionally yields the desired robustness properties against unknown but bounded external disturbances. Convergence and robustness properties of the proposed design are supported by simulation results.

The fifth paper, ”H_∞ Filtering for Switched Nonlinear Systems under Asynchronous Switching,” by W. Xiang and J. Xiao, addresses the H_∞ filtering problem for switched nonlinear systems under synchronous and asynchronous switching. First, H_∞ filtering under synchronous switching is investigated; however, the H_∞ filtering performance cannot be guaranteed if there exists asynchronous switching, as shown in a given numerical example. The asynchronous case is treated starting with the totally asynchronous switching; then, using the results in the synchronous and totally asynchronous cases, H_∞ filtering under partially asynchronous switching is considered. Several numerical examples are given to illustrate the effectiveness of the obtained results.

The next paper, ”Fuzzy H_∞ Filtering for Nonlinear Markovian Jump Neutral Delayed Systems,” by H. Shen, S. Xu, J. Zhou, and J. Lu, is concerned with the problem of the H_∞ filter design for nonlinear Markovian jump neutral systems through Takagi-Sugeno fuzzy model approach. A delay-dependent bounded real lemma (BRL) is presented in terms of linear matrix inequalities by employing a novel Markovian switched Lyapunov functional. Based on the derived BRL, both conventional H_∞ filter and non-fragile H_∞ filter are designed, which guarantee that the corresponding filtering error systems are stochastically stable with an H_∞ performance level. Finally, a numerical example is given to demonstrate the effectiveness of the results.

The seventh paper, "H_∞ Filtering for a Class of Switched Linear Parameter Varying Systems," by L. Zhang and P. Shi, addresses the filtering problem for a class of discrete-time switched linear parameter-varying systems under average dwell time switching. The stability result for general discrete-time switched systems with average dwell time is first presented. A mode-dependent full-order parameterized filter is then designed, and the corresponding existence conditions of such filters are derived via LMI formulation. The desired filter gains and admissible switching signals are obtained for a given system decay degree so that the resulting filter error system is exponentially stable and has a guaranteed H_∞ performance. A numerical example is given to demonstrate the potential and effectiveness of the developed theoretical results.

The last paper in the first group is the paper "Lyapunov-Based Design of Resilient Mixed MSE-Dissipative Type State Observers for a Class of Nonlinear Systems and General Performance Criteria," by E. Yaz, C. S. Jeong, and Y. Yaz, which is concerned with a class of continuous-time nonlinear system and measurement equations having locally incrementally conic nonlinearities and finite energy disturbances. A Lyapunov-based resilient mixed Mean Square Error (MSE)-Dissipative type state observer design approach is presented, which guarantees the satisfaction of MSE type estimation error performance together with a variety of dissipative performance criteria ranging from H_∞ to passivity of various types. Linear matrix inequalities are used to study feasibility of the solution. Simulation examples are included to illustrate and provide support to the effectiveness of the proposed design methodology.

The second group, "New Advances in H_∞ Control for Nonlinear Systems," opens with the paper "Central Suboptimal H_∞ Control Design for Nonlinear Polynomial Systems," by M. Basin, P. Shi, and D. Calderon-Alvarez. This paper presents the central finite-dimensional H_∞ regulator for nonlinear polynomial systems, which is suboptimal for a given threshold γ with respect to a modified Bolza-Meyer quadratic criterion including the attenuation control term with the opposite sign. In contrast to the existing results, the paper reduces the original H_∞ control problem to a corresponding optimal H_2 control problem. The paper yields the central suboptimal H_∞ regulator for nonlinear polynomial systems in a closed finite-dimensional form, based on the optimal H_2 regulator. Numerical simulations are conducted to verify the performance of the designed central suboptimal regulator for nonlinear polynomial systems against the central suboptimal H_∞ regulator available for the corresponding linearized system.

The second paper, "Reliable H_∞ Control for Discrete Uncertain Time-Delay Systems with Randomly Occurred Nonlinearities: The Output Feedback Case," by Y. Liu, Z. Wang, and W. Wang, is concerned with the reliable H_∞ output feedback control problem against actuator failures for a class of uncertain discrete time-delay systems with randomly occurred nonlinearities (RONs). The failures of actuators are quantified by a variable varying in a given interval. RONs are introduced to model a class of sector-like nonlinearities that occur in a probabilistic way according to a Bernoulli distributed white sequence with a known distribution. The time-varying delay is unknown with given lower and upper bounds. Attention is focused on the analysis and design of an output feedback controller such that, for all possible actuator failures, RONs, time delays, as well as admissible parameter uncertainties, the closed-loop system is exponentially mean-square stable and also achieves a prescribed H_∞ performance level. A linear matrix inequality (LMI) approach is developed to solve the addressed problem. A numerical example is given to demonstrate the effectiveness of the proposed design approach.

The third paper "Central Suboptimal Mean-Square H_∞ Controller Design for Linear Stochastic Time-Varying Systems," by M. Basin, S. Elvira-Ceja, and E. N. Sanchez, focuses on the central finite-dimensional H_∞ controller design for linear stochastic time-varying systems with integral-quadratically bounded deterministic disturbances, that is suboptimal for a given threshold γ with respect to a modified Bolza-Meyer quadratic criterion including the attenuation control term with the opposite sign. In contrast to the existing results, the paper reduces the original H_∞ controller problem to a corresponding optimal H_2 controller problem. Numerical simulations are conducted to verify the performance of the designed controller for a linear stochastic system against the central suboptimal H_∞ controller available for the corresponding deterministic system.

The next paper "Stability Analysis and Stabilization for a Class of 2-D Nonlinear Discrete Systems," by S. Ye and W. Wang, is concerned with stability analysis and stabilization problems for a class of two-dimensional (2-D) nonlinear discrete systems. First, the stability condition is derived for 2-D systems with nonlinearity by exploiting the Lyapunov method. Based on this result, a state feedback controller and an output feedback controller are designed to achieve stability for the resulting closed-loop system. Next, H_∞ controllers are given in terms of the linear matrix inequalities (LMIs). Numerical examples are given to illustrate the effectiveness of the obtained results.

The fifth paper "Semiactive Vibration Control of Nonlinear Structures through Adaptive Backstepping Techniques with H_∞ Performance," by M. Zapateiro, H. R. Karimi, and N. Luo, presents a new approach to the vibration mitigation problem in structures subject to seismic motions. This kind of structures are characterized by parameter uncertainties that describe their dynamics, such as stiffness and damping coefficients. Moreover, the dampers used to mitigate the vibrations caused by earthquakes are usually nonlinear devices with frictional or hysteretic dynamics. An adaptive backstepping controller is proposed to account for uncertainties and nonlinearities and satisfy a certain H_∞ performance level. It is designed for a 10-story building whose base is isolated with a frictional damper (passive device) and a magnetorheological damper (semiactive device). The controller performance is analyzed through numerical simulations.

The next paper, "Guaranteed Cost Control with Poles Assignment of a Flexible Air-Breathing Hypersonic Vehicle," by H. Li, Y. Si, L. Wu, and X. Hu, addresses the guaranteed cost control problem for a flexible air-breathing hypersonic vehicle (FAHV). A longitudinal model is adopted for control design due to the complexity of the vehicle. First, for a highly nonlinear and coupled FAHV, a linearized model is established around the trim condition which includes the state of altitude, velocity, angle of attack, pitch angle, pitch rate, etc. Second, using a Lyapunov approach, performance analysis is carried out for the resulting closed-loop FAHV system, whose criterion with respect to guaranteed performance cost and poles assignment is expressed in terms of linear matrix inequalities (LMIs). The established criterion exhibits a kind of decoupling between the Lyapunov positive-definite matrices to be determined and the FAHV system matrices, which is enabled by the introduction of additional slack matrix variables. Third, a convex optimization problem with LMI constraints is formulated for designing an admissible controller, which guarantees a prescribed performance cost with simultaneous consideration of pole assignment for the resulting closed-loop FAHV system. Finally, simulation results are provided to show that the guaranteed cost controller assigns the poles in the desired region and achieves excellent reference altitude and velocity tracking performance.

The seventh paper, "Delay-Dependent Robust H_∞ Control for Uncertain Stochastic Takagi-

Sugeno Fuzzy Systems with Time-Varying State and Input Delays," by P. Balasubramaniam and T. Senthilkumar, treats the delay-dependent robust H_∞ control problem for uncertain stochastic Takagi-Sugeno fuzzy systems with time-varying state and input delays. The parameter uncertainties are assumed to be time-varying and norm-bounded. Through constructing a new Lyapunov-Krasovskii functional, the delay-dependent robust H_∞ control algorithm is presented in terms of linear matrix inequalities (LMIs). A numerical example is given to illustrate the effectiveness of the developed method.

The last paper in the second group is the paper "Extending Nonlinear H_2, H_∞ Optimisation to $W_{1,2}$, $W_{1,\infty}$ spaces," by M. D. S. Aliyu and E. K. Boukas, which consists of two parts. Part I, "Optimal Control," states and solves the $W_{1,2}$, $W_{1,\infty}$ nonlinear optimal control problems as extensions of H_2, H_∞ optimal control problems, respectively. As these spaces contain less smooth functions, a larger number of problems could be solved in this framework, and, by a suitable choice of weighting functions, additional design objectives could be achieved using the presented formulation. Moreover, any solution to the $W_{1,p}$, $p = 2, \infty$, problem is automatically a solution to the corresponding H_p problem. Sufficient conditions for the solvability of the problems are given in terms of new Hamilton-Jacobi equations (HJEs). These new HJEs may also be easier to solve in view of additional degrees of freedom offered by the corresponding norms. Both the state-feedback and output-feedback problems are discussed. The results are then specialised to linear systems, in which case the solutions are characterised in terms of new algebraic Riccati equations.

Part II of the same paper, "Optimal Estimation and Output-Feedback Control," states and solves the $W_{1,2}$, $W_{1,\infty}$ estimation problems. The proportional, proportional-derivative and proportional-integral (PI) filters are proposed for each problem, and the sufficient conditions for existence of the optimal filter gains are obtained in terms of new Hamilton–Jacobi–Bellman and Hamilton-Jacobi-Isaacs equations. The output-feedback $W_{1,2}$ and $W_{1,\infty}$ control problems are also solved using the separation principle. It is shown that a viable optimal output-feedback controller can be synthesised by combining an optimal estimator with a state-feedback control.

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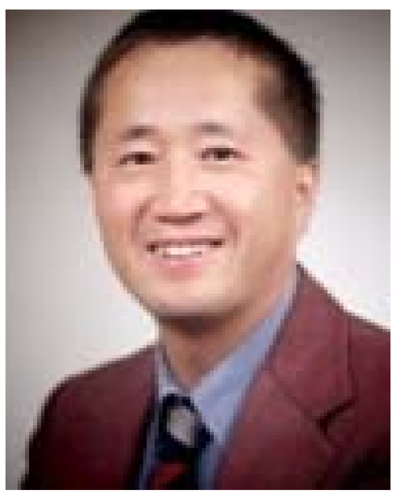
Michael V. Basin received his Ph.D. degree in Physical and Mathematical Sciences with major in Automatic Control and System Analysis from the Moscow Aviation Institute in

1992. His work experience includes Senior Scientist position in the Institute of Control Science (Russian Academy of Sciences) in 1992-96, Visiting Professor position in the University of Nevada at Reno in 1996-97, and Full-Time Tenured Professor position in the Autonomous University of Nuevo Leon, Mexico, from 1998.

Starting from 1992, Dr. Basin published a monograph, more than 80 research papers in international referred journals, and more than 130 papers in Proceedings of the leading IEEE and IFAC conferences and symposiums. He is the author of the monograph *"New Trends in Optimal Filtering and Control for Polynomial and Time-Delay Systems,"* published by Springer. His works are cited more than 600 times. He is the Editor-in-Chief of *Journal of The Franklin Institute*, an Associate Editor of the *IEEE Control System Society Conference Editorial Board*, *Automatica*, *International Journal of Systems Science*, *International Journal of Innovative Computing, Information and Control*, and other journals. Dr. Basin serves as a member of *IEEE Control System Society Technical Committee on Intelligent Control*, Program Committee member of *IEEE Conference on Decision and Control 2008, IEEE Conference on Control Applications 2009, IEEE International Conferences on Innovative Computing, Information and Control 2006–2010, IEEE Workshop on Variable Structure Systems 2010, Mexican Automatic Control Conferences 2006, 2008*. Dr. Basin was awarded a title of Highly Cited Researcher by Thomson Reuters (International Science Institute), the publisher of Science Citation Index, in 2009; he is a Senior Member of the IEEE Control Systems Society and a regular member of the Mexican Academy of Sciences. His research interests include optimal filtering and control problems, stochastic systems, time-delay systems, identification, sliding mode control and variable structure systems.



Peng Shi received the BSc degree in Mathematics from Harbin Institute of Technology, China, in 1982; the ME degree in control theory from Harbin Engineering University, China in 1985; the PhD degree in electrical engineering from the University of Newcastle, Australia in 1994; and the PhD degree in mathematics from the University of South Australia in 1998. He was awarded the degree of Doctor of Science by the University of Glamorgan, UK, in 2006.

Dr. Shi was a lecturer in Heilongjiang University, China (1985-1989), in the University of South Australia (1997-1999) and a senior scientist in Defence Science and Technology Organisation, Department of Defence, Australia (1999-2005). He joined in the University of Glamorgan, UK, as a professor in 2004. He is also a professor at Victoria University, Australia since 2008. Dr. Shi's research interests include robust control and filtering, fault detection techniques, Markov decision processes, and operational research. He has published a number of papers in these areas. In addition, Dr. Shi is a co-author of the three research monographs, Analysis and Synthesis of Systems with Time-Delays (with Y. Xia and M. Fu, Berlin, Springer, 2009), Fuzzy Control and Filtering Design for Uncertain Fuzzy Systems (with W. Assawinchaichote and S. K. Nguang, Berlin, Springer, 2006), and Methodologies for Control of Jump Time-Delay Systems (with M. Mahmoud, Boston, Kluwer, 2003).

Dr. Shi currently serves as Editor-in-Chief of Int. J. of Innovative Computing, Information and Control. He is also an Associate Editor/Editorial Board Member for several other journals, including IEEE Transactions on Automatic Control, IEEE Transactions on Systems, Man and Cybernetics-Part B, IEEE Transactions on Fuzzy Systems, and Int. J. of Systems Science. He is the recipient of Most Cited Paper Award of Signal Processing in 2009. Dr. Shi is a Fellow of Institute of Mathematics and its Applications (UK), and a Senior Member of IEEE.