Stability, Oscillations and Optimization of Systems
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Volume 11

ADVANCES IN STABILITY AND CONTROL THEORY FOR UNCERTAIN DYNAMICAL SYSTEMS

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This multiauthor volume consists of sixteen chapters presenting the results of theoretical research and engineering applications of some uncertain systems.

The volume comprises four parts:

- I Stability and Control in Uncertain Systems
- II Stability and Stabilization in Discrete-Time Systems
- III Synchronization in Dynamical Systems
- IV Engineering Applications

In recent decades, the problems of stability and control of systems with uncertain parameters values have received much attention in many areas including biology, chemistry, optics, electronics, mechanics, economics. This volume is intended to provide a useful source of reference for graduates, postgraduates, researchers and professionals working in these areas.

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CONTENTS

AN OVERVIEW

Survey of Part I

Stability and Control in Uncertain Systems

This part comprises four chapters with detailed studies on stability and control problems in uncertain systems, and it is organized as follows:

Chapter 1, contributed by Ye-Hwa Chen, Xiaomin Zhao and Daisheng Zhang. The problem of designing controls for a linear dynamic system under input disturbance is considered. The input disturbance is bounded but the bound information is either deterministic or fuzzy. The control design is purely deterministic. However, the resulting system performance is interpreted differently, depending on the bound information. It may be deterministic or fuzzy (i.e. with a spectrum of outcome to various degrees). Finally, the optimal design problem of the control scheme, in which the cost is in quadratic form, is solved.

Chapter 2, contributed by Yu.A. Martynyuk-Chernienko, considers a class of uncertain dynamical systems and sufficient conditions, in terms of matrix-valued Lyapunov functions are provided for the new concept of stability and uniform asymptotic stability.

In *Chapter 3*, contributed by A. G. Mazko, the author gives an overview of some problems of output feedback stabilization, robust stabilization, quadratic optimization and generalized H_∞-control for some classes of linear and nonlinear dynamical systems. Sufficient stability conditions for the zero state are formulated with the joint quadratic Lyapunov function for a family of control systems with uncertain coefficient matrices. The solution of robust stabilization problem and evaluation of the quadratic performance criterion for nonlinear control systems are proposed. Methods for construction of control laws providing a robust stability and specified evaluation of the weighted damping level of input signals and initial perturbations are proposed for a class of linear systems with controllable and observable outputs. The application of the main results reduces to solving the systems of linear matrix inequalities.

Chapter 4, contributed by MingQing Xiao and T. Başar. It is well-known that the Hamilton-Jacobi-Isaacs (HJI) equation associated with a nonlinear H_∞-optimal control problem on an infinite-time horizon generally admits nonunique, and in fact infinitely many, viscosity solutions. This makes it difficult to pick the relevant viscosity solution for the problem at hand, particularly when it is computed numerically. For the finite-horizon version of the problem, however, there is generally a unique viscosity solution (under appropriate conditions), which brings up the question of obtaining the viscosity solution relevant to the infinite-horizon problem as the limit of the unique solution of the finite-horizon one. This chapter addresses this question for nonlinear systems affine in the control and the disturbance, and with a cost function quadratic in the control, where the control is not restricted to lie in a compact set. It establishes the existence of a well-defined limit, and also obtains a result on global asymptotic stability of closed-loop system under the H_∞ controller and the corresponding worst-case disturbance.

Survey of Part II

Stability and Stabilization in Discrete-Time Systems

Part II comprises four chapters, which are devoted to discrete-time dynamical systems as follows:

In *Chapter 5*, contributed by A.Yu. Aleksandrov and J. Zhan, a class of discrete-time nonlinear positive switched systems with delay is studied. Sufficient conditions of the existence of common Lyapunov–Krasovskii functionals for the associated families of subsystems are found. With the aid of a modification of the constructed functionals, estimates of the convergence rate of solutions are derived. For the case where we can not guarantee the existence of common Lyapunov–Krasovskii functionals, conditions on switching laws are obtained providing the asymptotic stability of the zero solutions of the corresponding switched systems. An example is given demonstrating the validity of the results.

Chapter 6, contributed by Guoping Lu, Daniel W.C. Ho and Lei Zhou, discusses the quadratic stability and quadratic stabilization problem for a class of nonlinear perturbed discrete time-delay systems. Necessary and sufficient conditions for quadratic stability are presented via S-procedure technique and linear matrix inequality (LMI). Both static and dynamic output feedback controllers are constructed respectively. Furthermore, necessary and sufficient conditions for quadratic stabilization via static state feedback are constructed in the form of LMI. Finally, the effectiveness of new approach is demonstrated by numerical examples.

Chapter 7, contributed by A. G. Mazko, is devoted to the problems of output feedback stabilization, robust stabilization, quadratic optimization and generalized H_∞-control for a class of affine discrete-time systems. The solution of robust stabilization problem and evaluation of the quadratic performance criterion for a family of nonlinear nonautonomous control systems are proposed. Methods for construction of control laws providing a robust stability and specified evaluation of the weighted damping level of input signals and initial perturbations are proposed for linear systems with controllable and observable outputs. The application of the main results reduces to solving the systems of linear matrix inequalities.

Chapter 8, contributed by B. Sfaihi, M. Benrejeb and P. Borne, deals with stability of discrete-time nonlinear Lur'e-type systems. Through the singular perturbations technique, the original system is reduced to a block-diagonal form with slow and fast decoupled modes. Stability conditions of the two-time-scale decoupled model based on Borne-Gentina practical stability criterion and the use of matrices in the Benrejeb arrow form are developed and compared with those concerning the original discrete-time system. It is shown that these results are practical and less conservative than the existing ones. A third order system is introduced to illustrate the efficiency of the proposed approach.

Survey of Part III

Synchronization in Dynamical Systems

This part of the book consists of three chapters reviewing synchronization in dynamic systems and is structured as follows:

Chapter 9, contributed by A. Othman Almatroud, M.S.M. Noorani and M. Mossa Al-Sawalha, mainly concerns the general methods for the function projective dual synchronization of a pair of chaotic systems with unknown parameters. The adaptive control law and the parameter update law are derived to make the states of a pair of chaotic systems asymptotically synchronized up to a desired scaling function by Lyapunov stability theory. The general approach for function projective dual synchronization of Lü system and Lorenz system is provided. Numerical simulation results show that the proposed method is effective and convenient.

Chapter 10, contributed by R.L. Filali, S. Hammami, M. Benrejeb and P. Borne. Suitable stabilization conditions are proposed, for master and slave hyperchaotic discrete-time systems. The proposed approach, leading to these conditions for complete synchronization, anti-synchronization and hybrid synchronization phenomena studies, is based on the use of state feedback and aggregation techniques for stability and stabilizability studies associated with the Benrejeb arrow form matrix for system description. The results, easy to use, are successfully applied for two identical 3D generalized Hénon maps.

Chapter 11, contributed by A. Khan and R. Pal. Adaptive hybrid function projective synchronization between two identical chaotic space-tether systems having uncertain time-varying parameters has been achieved. Based on Lyapunov stability theory, adaptive control laws and parameter update laws for estimating the uncertain, time-varying parameters are derived to make the states of the two identical chaotic systems asymptotically synchronized. Complete synchronization, antisynchronization, hybrid projective synchronization are obtained as special cases from the above synchronization method. Time series graphs of the estimated parameters and the error variables verify the control techniques and the proposed update laws.

Survey of Part IV

Engineering Applications

Part IV of the book comprises five chapters devoted to the engineering applications of control and systems theory, organized as follows:

Chapter 12, contributed by A.Yu. Aleksandrov, E.B. Aleksandrova and A.A. Tikhonov, deals with the problem of monoaxial attitude stabilization of a rigid body. The possibility of implementing such a control system in which the restoring torque tends to zero as time increases is studied. With the aid of the Lyapunov direct method and the differential inequalities theory, conditions under which an equilibrium position of the body is stable with respect to all variables as well as with respect to a part of variables are derived. In addition, it is shown that the proposed approaches can also be used in the problem of the triaxial stabilization of a rigid body. A numerical example is presented to demonstrate the effectiveness of the obtained results.

In *Chapter 13*, contributed by Mohit Makkar and Jean-Yves Dieulot, a passivity based model of a general set of bio-reactions in open reactors with new energy functions is derived. A change of coordinates is done, based on the stoichiometric invariance principle, which simplifies the number of equations to be taken care of and shows directly the passivity of the system. The passivity based control will be obtained in terms of systematic controller design techniques. The energy functions can be said to be in close proximity with the Gibbs free energy function used in port-Hamiltonian model of enzymatic reactions and are far from the traditional non-physical quadratic functions. An adaptive control law can be found which preserves the passivity properties.

In *Chapter 14*, contributed by M. Sharma and A. Verma, a novel Huang-Hilbert Transform (HHT) based adaptive tracking control strategy is proposed for a class of uncertain systems subjected to actuator saturation. HHT is used in this work for the online feature extraction of the uncertainties in the systems which are approximated by Wavelet Neural Networks (WNNs). Adaptation laws are developed iteratively using the Intrinsic Modal Functions (IMF) for the online tuning of wavelets parameters. The uniformly ultimate boundedness of the closed-loop tracking error is verified even in the presence of WNN approximation errors and bounded unknown disturbances, using the Lyapunov approach and with novel weight updating rules. Finally some simulations are performed to verify the effectiveness and performance of the theoretical development.

Chapter 15, contributed by A. Tlemçani, N. Henini and H. Nouri, develops an adaptive fuzzy control of nonlinear system class. In this method, we investigated the possibilities offered by the fuzzy systems of Takagi-Sugeno type in terms of approximation capacity of the continuous nonlinear functions and we exploited the Lyapunov theory to establish a parametric adaptation law, ensuring the total stability of the system. Finally, simulation results are presented to show the effectiveness of this kind of controller.

Chapter 16, contributed by Sheng-Guo Wang, P.N. Roschke and H.Y. Yeh. Although control theory has been widely applied to constrain motion response of tall, slender structures and long bridges undergoing large forces from natural hazards such as earthquakes and strong winds, numerous uncertainties in these structures such as model errors, stress calculations, material properties, and load environments need to be included in design of the control algorithm. This chapter develops a robust active control approach to treat structured uncertainties in the system, control input, and especially, disturbance input matrices that have not been treated previously. Special SVD decomposition is applied to all forms of the structured uncertainties. Robust active control provides multi-objectives, including robust α-degree relative stability, robust H_∞ disturbance attenuation and robust H_2 optimality. The H_∞ norm of the transfer function from the external disturbance forces (e.g., earthquake, wind, and etc.) to the observed system states is restricted by a prescribed attenuation index δ. Settling time of the controlled structural system is robustly less than $4/\alpha$. Preservation of robust H_2 optimality of any uncertain structural systems with the admissible structured uncertainties by the proposed robust control is also discussed and proved. Numerical simulations of a four-story building under robust control are carried out for motion induced by the 1940 El Centro earthquake. Evaluation of controller performance is measured by application of six indices, including a comparison with an LQR controller. Results of the proposed approach may be applied to robust control design of structural systems.