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Control of Uncertain Systems with Bounded Inputs

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Preface

In a practical control problem, many constraints have to be handled in order to design controllers which operate in a real environment. The first step in a control problem is to find an appropriate model for the system. It is well-known that this step, if successfully applied (that is, if the model gives an accurate representation of physical phenomena) leads usually to a satisfactory control law design, satisfactory meaning that the observed behavior of the real controlled system is conform with the desired results.

A model can be derived in several ways. The most direct approach consists in applying general physical laws, decomposing the modelling problem into subproblems, solving each of them and by some more or less simple manipulations, deriving a complete model. Obviously, this method is based on some strong a priori knowledges and then some approximations are usually considered.

For some systems, the previous approach is difficult to implement because the application of physical laws is practically impossible or simply because only a partial knowledge on the system is available. In this case, the system is considered as a black box and a model is elaborated from experimental data (identification). Some crucial choices have to be done in order to derive a satisfactory model, these choices concerning essentially the input, the model order and model structure.

It is also possible to combine the two previous methods. An a priori knowledge on the system is then combined with identification tools. The model structure results from the a priori knowledge while the model parameters are obtained by an identification method.

In conclusion, to obtain a model using one of the above approaches, it is often necessary to approximate or neglect some phenomena, or to choose some key parameters. A direct consequence is that the derived model is affected by some uncertainties. To find a control operating in a real environment, uncertainties have to be appropriately described and their effects considered in the control law design (Robust Control). Some potential results on robust control have been widely developed these last decades and although, some intensive works continue to be developed, this domain has attained a certain maturity degree.

Concerning the control, practically the control is bounded and saturations can occur, these problems being the consequence of actuators limitations. It is also important to include them in the control law design (Constrained Control). A large amount of works has been done in this way and several approaches were developed in the literature.

It seems to be fundamental to combine the results obtained in these two fields in order to derive some methodologies with practical interest and therefore to design some controllers capable of achieving acceptable performances under uncertainty or disturbance and design constraints. For two or three years, a significative effort is done in this sense. This book entitled "*Control of Uncertain Systems with Bounded Inputs*" is aimed to give a good sample, not exhaustive of course, of what it was done up to now in the field of robust and constrained control design. The idea is to propose a collection of papers in which some fundamental ideas and concepts are proposed, each paper constituting a chapter of the book. The book is organized as follows.

Chapter 1. Feedback Control of Constrained Discrete-Time Systems
by E. De Santis

In this chapter, the author considers a linear discrete-time system with exogenous disturbances and with bounded inputs and states. The problem of controlling such a system is addressed. Conditions are proposed for the existence of state feedback controllers that achieve a level of performance with respect to some given criteria. An additional requirement is that the undisturbed system is asymptotically stable. If the problem has solution, the subclass of controllers that achieve the highest level of robustness, with respect to given parametric uncertainties in the system matrices, is determined.

Chapter 2. $\mathcal{L}^2$-Disturbance Attenuation for Linear Systems with Bounded Controls : an ARE-Based Approach
by R. Suárez, J. Alvarez-Ramírez, M. Sznaier, C. Ibarra-Valdez

Linear continuous-time systems with additive disturbance and bounded controls are considered. A technique for obtaining a bounded continuous feedback control function is proposed in order both to make globally stable the closed-loop system and to satisfy an $\mathcal{L}_2$ to $\mathcal{L}_2$ disturbance attenuation in a neighborhood of the origin. The solution is given in terms of solutions to an algebraic parametrized Riccati equation. The proposed control is then a linear-like feedback law with state-dependent gains.

Chapter 3. Stability Analysis of Uncertain Systems with Saturation Constraints
by A.N. Michel and L. Hou

This chapter addressed new sufficient conditions for the global asymptotic stability of uncertain systems described by ordinary differential equations under saturation constraints. Systems operating on the unit hypercube in $\Re^n$ (where all states are subject to saturation constraints) and systems with partial state saturation constraints (where only some of the states are subject to constraints) are studied. These types of systems are widely used in several areas of applications, including control systems, signal processing, and artificial neural networks. The usefulness of the proposed results is shown by means of a specific example.

Chapter 4. Multi-Objective Bounded Control of Uncertain Nonlinear Systems : an Inverted Pendulum Example
by S. Dussy and L. El Ghaoui

Considering a nonlinear parameter-dependent system, an output feedback controller is sought in order for the closed-loop system to satisfy some specifications as stability, disturbance rejection, command input and output peak bounds. The controller state space matrices are allowed to depend on a set of measured parameters and/or states appearing in the nonlinearities. The specifications have to be robustly satisfied with respect to the remaining (unmeasured) parameters and/states appearing in the nonlinearities. Sufficient conditions are derived to ensure the existence of such a mixed gain-scheduled/robust controller. These conditions are LMIs, associated with a set of nonconvex conditions. An efficient heuristic to solve them is proposed. The design method is illustrated with an inverted pendulum example.

Chapter 5. Stabilization of Linear Discrete-Time Systems with Saturating Controls and Norm-Bounded Time-Varying Uncertainty
by S. Tarbouriech and G. Garcia

Discrete-time systems with norm-bounded time-varying uncertainty and bounded control are considered. From the solution of a discrete Riccati equation a control gain and a set of safe initial conditions are derived. The asymptotic stability of the closed-loop system is then locally guaranteed for all admissible uncertainties. The connections between these results and the disturbance rejection problem are investigated. The class of perturbations which can be rejected in presence of saturating controls is characterized. The results are illustrated with the discretized model of the inverted pendulum. Furthermore, the approach by LMIS is discussed.

Chapter 6. Nonlinear Controllers for Constrained Stabilization of Uncertain Dynamic Systems
by F. Blanchini and S. Miani

The problem of determining and implementing a state feedback stabilizing control law for linear continuous-time dynamic systems affected by time-varying memoryless uncertainties in the presence of state and control constraints is addressed. The properties of the polyhedral Lyapunov functions, i.e. Lyapunov functions whose level surfaces aretheir capability of providing an arbitrarily good approximation of the maximal set of attraction, which is the largest set of initial states which can be brought to the origin with a guaranteed convergence speed. First the basic theoretical background needed for the scope is recalled. Some recent results concerning the construction of the mentioned Lyapunov functions and the controller implementation are reported. Finally, the results of the practical implementation on a two-tank laboratory system of a linear variable-structure and a quantized control law proposed in literature is presented.

Chapter 7. H_∞ Output Feedback Control with State Constraints
by A. Trofino, E.B. Castelan, A. Fischman

In this chapter, a biconvex programming approach is presented for the design of output feedback controllers for discrete-time systems subject to state constraints and additive disturbances. The method proposed is based on necessary and sufficient conditions for the existence of stabilizing static output feedback controllers. Mixed frequency and time domain specifications for the closed-loop system like H_∞ performance requirements and state constraints in the presence of disturbances are investigated.

Chapter 8. Dynamic Output Feedback Compensation for Systems with Input Saturation
by F. Tyan and D.S. Bernstein

This chapter deals with optimization techniques to synthesize feedback controllers that provide local or global stabilization along with suboptimal performance for systems with input saturation. The approach is based upon LQG-type fixed-structure techniques that yield both full and reduced-order, linear and nonlinear controller. The positive real lemma provides the basis for constructing nonlinear output feedback dynamic compensators. A major aspect of the presented approach is the guaranteed subset of the domain of attraction of the closed-loop system. The results are then illustrated with several numerical examples.

Chapter 9. Quantifier Elimination Approach to Frequency Domain Design
by P. Dorato, W. Yang, C. Abdallah

Quantifier-elimination methods are proposed for the design of fixed structure compensators which guarantee robust frequency domain bounds. It is shown for example, that robust stability and robust frequency domain control-effort constraints, can be reduced to system of multivariable polynomial inequalities, with logic quantifiers on the frequency variable and plant-parameter variables. Quantifier-elimination software can then be used to eliminate quantifier variables and to obtain quantifier-free formulas which define sets of admissible compensators parameters.

Chapter 10. Stabilizing Feedback Design for Linear Systems with Rate Limited Actuators
by Z. Lin, M. Pachter, S. Banda, Y. Shamash

This chapter considers two design techniques recently developed for linear systems with position limited actuators : piecewise-linear LQ control and low-and-high gain feedback. These techniques are combined and applied to the design of a stabilizing feedback controller for linear systems with rate-limited actuators. An open-loop exponentially unstable F-16 class fighter aircraft is used to demonstrate the efficiency of the proposed control design method. The proposed combined design takes advantages of these techniques while avoiding their disadvantages.

We hope that this book would highly contribute to significative developments in the field of robust and constrained control, and would be a reference for future investigations in this field.

Toulouse, April 8, 1997.

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