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Book review

H_∞ control and its applications
Ben M. Chen; Springer, London, 1998,
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Due to its fascinating theoretical as well as its proven practical applicability, the so-called H_∞-control problem has drawn considerable attention since its explicit formulation by Zames (1981). Although the misnomer H_∞ is associated in the literature with a variety of concrete problem formulations, the book under review is confined to the disturbance attenuation problem for linear time-invariant finite-dimensional systems: For a given system, design a controller that feeds a measured signal back to a control input such that the effect of a disturbance entering the system onto a controlled output signal is reduced as far as possible where the quality of the attenuation is measured in terms of the controlled system's energy gain. Despite this innocent formulation, the real attraction of this problem results from numerous other concrete and practically important tasks that can be subsumed to this simple scenario, such as shaping the transfer matrix of a control system through a suitable controller (loop-shaping) or rendering a system not only nominally but even robustly stable against a well-defined class of uncertainties (robust stabilization).

The theoretical parts of the book under review are entirely devoted to questions of how to compute the optimal attenuation level, of how to design controllers that achieve these levels as closely as desired, and of characterizing when the attenuation level can be rendered arbitrarily small, what amounts to the solvability of the so-called almost disturbance decoupling problem. As the main theme, the author demonstrates in a detailed and complete fashion how to answer these questions both for discrete- and continuous-time systems by using as a main tool the so-called special coordinate basis for a control system in which the various controlled- and conditioned-invariant subspaces from geometric control theory admit a very simple description. Two realistic design examples serve to demonstrate how the explicit controller design algorithms perform both in simulation and in real-time implementation.

After an overview over the relevance of H_∞-control and an exact problem formulation in the time domain in Chapter 1, the author turns to a computation-oriented description of canonical forms for matrices and matrix pairs as well as for system matrices in Chapter 2. The center stage is taken by a refinement of the so-called special coordinate basis with a careful discussion of how to extract in these specific coordinates all relevant algebraic objects that are defined in geometric control, such as the finite- and infinite-zero structure, largest controlled invariant and controllability subspaces as well as their duals, and the relation to the underlying system's invertibility properties. Since all these intimate relations do appear only in a rather scattered fashion in the literature, the authors' merit is to provide a pretty complete picture with detailed arguments of how to prove the various connections what renders the subject accessible for a novice to geometric control. We regret the decision of the author to demonstrate only by means of an example how the actual transformation of a general system has to be performed. Chapter 3 is devoted to the so-called suboptimality tests, verifiable conditions for the existence of controllers that achieve a certain desired level of disturbance attenuation. The author provides a collection of various tests in terms of the solvability of quadratic matrix inequalities and Riccati equations or inequalities literally as they appear in the literature, among them the famous two Riccati equation solution from the breakthrough work (Doyle, Glover, Khargonekar & Francis 1989). Chapter 4 comprises a thorough investigation of the transformation properties of geometric subspaces and Riccati equations if transforming the underlying system from a discrete-time into a continuous-time description. Although it is conceptually a bit unclear why the inherent symmetry is broken and the corresponding Caley transformation and its inverse are treated separately, this chapter provides a very complete and fully proved reference list of relations that are useful for a variety of problems that involve the translation of continuous- to discrete-time results. As an impressive demonstration, it is revealed in Chapters 8–10 how these preparations render the proofs of H_∞-results for discrete-time systems almost into a routine exercise.

The Chapters 5–7 dealing with continuous-time systems together with the discrete-time counterparts of Chapters 8–10 form the central part of the book in demonstrating the power of the geometric approach in combination with the special coordinate basis to arrive at deep insights into how the achievable attenuation level is influenced by the various geometric properties of the underlying system.

The main topic in Chapters 5 and 8 is to give an explicit formula for the optimal attenuation level in the

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state-feedback and the output-feedback problem. This is possible under certain specific geometric conditions which ensure that the only cause for a non-zero attenuation level are closed-right plane invariant zeros of the two systems mapping the control input to the controlled output and the disturbance input to the measured output. These requirements are always satisfied if these two subsystems are right- and left-invertible respectively, what corresponds to considering a one-block problem (Francis & Doyle, 1987) in the operator-theoretic approach. Under these hypothesis, it is only required to transform the system into special coordinates and to solve well-defined Riccati-, Sylvester- and Lyapunov-equations in order to provide a formula for the optimal attenuation level in terms of these solutions. The required steps to be followed are presented in an algorithmic fashion what considerably simplifies the numerical implementation of these techniques.

Chapters 6 and 9 are devoted to controller construction if a certain attenuation level has been found achievable. The author follows a standard approach in first providing a step-by-step algorithm for the construction of state-feedback gains and then combining it with the dual observer gain construction in order to arrive at full order output-feedback controllers. The various properties of the resulting closed-loop systems, and here in particular the freedom in placing the closed-loop poles, are exhibited in detail. Finally, the design of reduced-order controllers is very nicely motivated by system theoretical arguments that reveal why signals in a certain subspace need not be dynamically reconstructed.

In Chapters 7 and 10, all these insights are specialized to the case in which the optimal attenuation level vanishes what is equivalent to the solvability of the almost disturbance decoupling problem. Special emphasis is put on the explicit construction of parameterized families of state-feedback and full-order as well as reduced-order output-feedback laws that allow to render the attenuation level as close to zero as desired.

Chapters 11 and 12 discuss the application of almost-disturbance decoupling to a piezoelectric actuator system with simulation results and to the stabilization of a mirror targeting system with an actual hardware implementation.

Finally, Chapter 13 poses as an open problem the explicit computation of the optimal disturbance attenuation level without any geometric hypothesis. A partial answer for the corresponding state-feedback problem might be found in Scherer (1990, 1994), by providing a computable candidate value together with algebraically verifiable conditions in order to test whether the candidate value indeed equals the optimal attenuation level.

We summarize that this book is an excellent research reference for insights and proofs pertaining to the geometric approach in H_∞-control. The careful and detailed exposition illustrates the far-reaching potentials of these techniques for a variety of other control problems beyond H_∞-theory. Throughout the book the author chooses an algorithmic style of presenting the sometimes rather intricate constructions in favor of their numerical implementation. Moreover, by splitting the subjects into suboptimality tests, computation of optimal values, controller construction, and almost disturbance decoupling, he renders all these themes accessible for independent investigation. At some points it would have been desirable to include somewhat more detailed remarks on their close interrelation in the main text. However, these relations are carefully worked out in the detailed and complete proofs that accompany each of these subjects what allows the reader to grasp the rationale behind the various constructive design steps. We therefore believe that this book closes a gap in literature by providing a thorough basis for entering the rich field of applying geometric techniques in H_∞-control.

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About the reviewer

Carsten Scherer received his diploma degree and his Ph.D. degree in Mathematics from the University of Würzburg (Germany) in 1987 and 1991 respectively. In 1989, Dr. Scherer spent six months as a visiting scientist at the Mathematics Institute of the University of Groningen. In 1992, he was awarded a grant from the Deutsche Forschungsgemeinschaft (DFG) for six months of post doctoral research at the University of Michigan (Electrical Engineering and Computer Science) and at Washington University (Systems Science and Mathematics) respectively. In 1993, Dr. Scherer joined the Mechanical Engineering Systems and Control Group at Delft University of Technology (The Netherlands) where he currently holds a position as an associate professor. In 1999 he spent a three months sabbatical as a visiting professor at ETH-Zürich (Automatic Control Laboratory). His main research interests cover various topics in applying optimization techniques for developing new advanced controller design algorithms and their application to mechatronics and aerospace systems.