Book Reviews

In this section, the IEEE Control Systems Society publishes reviews of books in the control field and related areas. Readers are invited to send comments on these reviews for possible publication in the Technical Notes and Correspondence section of this TRANSACTIONS. The CSS does not necessarily endorse the opinions of the reviewers.

If you have used an interesting book for a course or as a personal reference, we encourage you to share your insights with our readers by writing a review for possible publication in the TRANSACTIONS. All material published in the TRANSACTIONS is reviewed prior to publication. Submit a completed review or a proposal for a review to:

D. S. Naidu
Associate Editor—Book Reviews
College of Engineering
Idaho State University
833 South Eighth Street
Pocatello, ID 83209

Robust Control: Systems with Uncertain Physical Parameters—Jürgen Ackermann et al. (New York: Springer-Verlag, 1993).
Reviewed by M. Mansour.

I. DESCRIPTION

This book deals with robust control of systems with uncertain physical parameters where emphasis is given to the word "physical." The problem formulation is derived mainly from practical situations as opposed to the merely theoretical ones. Recent books dealing with the same problem, with similar and other aspects, are given in [1]–[3]. Kogan [3] gives a theoretical analysis of the robust stability problem of linear systems with parameter perturbations including multidimensional and time-delay systems. Barmish [1] deals with mathematical tools for dealing with the robustness problem with parameter perturbations giving one case study to demonstrate part of the theory. Bhattacharyya et al. [2] gives a more comprehensive study of the same problem with two case studies applying the theoretical results. It also includes consideration of parametric as well as unstructured uncertainty.

In the first part of the book the authors give models of four practical systems as motivation to the analysis and design methods described in the following chapters. These examples are: a crane, a four-wheel car steering, an automatic car steering, and flight control of a fighter aircraft. The first example has a fourth-order linearized model with three uncertain parameters, the second example has a second-order linearized model with two control variables and two uncertain parameters, the third example has a fourth-order linearized model with two control variables and one uncertain parameter, and the fourth example has a third-order linearized model with two uncertain parameters. The examples are used to test the applicability of the different methods developed throughout the book. The authors also show in this part how the sensor and controller structures are chosen to facilitate the robustness design problem.

The second part deals with the stability analysis of polynomial families. Here the main mathematical tools are developed, where the basic principles and important results such as the boundary crossing theorem, the Khartitonov theorem, the Edge theorem, the mapping theorem, the zero exclusion principle and the value set concept, are dealt with in a clear and systematic way. Several stability test methods such as algebraic tests, tests in the root plant and in the parameter space, as well as frequency plot tests are reviewed and applied to uncertain polynomials. For the case of interval polynomials, polynomials with coefficients affine functions of the parameters, Khartitonov theorem, and the Edge theorem, respectively, are the right tools to solve the robust stability problem. For polynomials with coefficients multilinear functions of the parameters, the mapping theorem yields a useful sufficient stability test using the convex hull of the vertices of the parameters for the value set and applying the zero exclusion concept. It is shown that the actual value set can be obtained using the Jacobian condition. An interesting section in this second part is the derivation of the value set for nonlinear parameter dependency if the characteristic equation has special properties. Algorithms for elementary value set operations such as addition and multiplication are used to get the value set of characteristic equations which can be rewritten in a form allowing the use of these algorithms. An algorithm for the tree-structured decomposition is useful in this case. The value set can thus be obtained by a computer program.

The last section of Part II is concerned with the determination of the stability radius. First the method of Tytykin–Poyak is described. It allows the determination of the stability radius using frequency sweeping. The method of Kaczur and Ackermann is used to determine the largest hypersphere in the parameter space if the polynomial coefficients are affine functions of the parameters. Here, only one function has to be evaluated. For polynomial dependency on the parameters, it is shown that determining the stability radius is reduced to solving a finite set of algebraic equations. Here, numerical algorithms have to be used.

The third part deals with robustness analysis of feedback systems. The Box theorem of Chapellat and Bhattacharyya is used to determine the robust stability of single-loop feedback systems with interval plant. The connection between strict positive real functions and robust stability of feedback systems is obtained. The idea of tree-structured uncertain polynomials of Part II is extended to investigating the robust stability of control systems where the uncertainty is somewhat more general. If the roots of the characteristic polynomial of the uncertain system are confined to a certain region gamma in the complex plane, then one speaks of gamma stability. This part of the book shows how the region gamma can be chosen and how the boundary crossing idea...
can be applied as well as how the value set can be obtained. The same ideas for the investigation of stability of continuous systems can be extended or modified to suit the investigation of sampled-data control systems. The last section of Part III deals with this problem.

Part IV deals with design tools for robust stabilization of a finite number of plants. Two design tools are presented, one using the design of the parameter space introduced by Ackermann in 1980 where a gamma region is chosen for the eigenvalues of the closed loop system, and regions for the feedback parameters are determined. A cross-section plane is chosen according to a systematic approach to get the gamma-stabilizing feedback controller. The other tool is designing the controller by optimizing a vector performance index introduced by Kreisselmeier and Steinhausen in 1979. These design tools are applied to some of the practical examples of Part I.

II. CONCLUSION

In summary, this well-written book is suitable for graduate students and practicing engineers dealing with robust control. The extensive use of practical examples to demonstrate the usefulness of the developed theoretical and computational algorithms distinguishes this book from others in the area of robust control. The practical examples as well as the algorithms are partly developed by the first author and his coworkers.

This book is restricted to the case of parameter uncertainties and does not treat other methods of robust control such as $H_\infty$-optimization, $\mu$-synthesis, and the Lyapunov approach. As mentioned by the authors, some recent contributions in the area of parameter uncertainties have been left out. However, I think that the authors have succeeded in bringing together the fundamental principles which are of major importance for the ability to follow the development of the subject. They have to be commended for this excellent work.

REFERENCES


Dynamical systems appear quite naturally in connection with optimization problems. Just think of unconstrained optimization and corresponding gradient flows. Equality constraints generically define a submanifold in an Euclidean space. The corresponding projected gradient flow yields essential information about properties of first-order algorithms for solving the optimization problem. There exist several ways to reduce optimization problems involving inequality constraints to ones with equality constraints only. We emphasize here two such methods which became popular recently in connection with so-called interior-point methods. The first method eliminates inequality constraints by introducing barrier functions. In the second method, one introduces a parameterization of the feasible set by a smooth manifold. If we return to an unconstrained optimization problem and assume that the cost function is twice continuously differentiable and has everywhere positive definite Hessian, one can consider the gradient flow relative to the metric defined by this Hessian. In this way we arrive at the continuous-time version of the Newton’s method.

In many cases it is quite natural to think of optimization algorithms as algorithms for numerical integration of corresponding continuous-time dynamical systems. It is usually much easier to analyze the qualitative behavior of solutions of continuous-time dynamical systems arising in optimization than their discrete-time counterparts. A good illustration of this point is given by the Newton’s method. The corresponding continuous-time dynamical system described above admits a global linearization by the Legendre transform defined by the cost function. This example illustrates another interesting property of dynamical systems related to optimization problems.

Very frequently such dynamical systems admit explicit solutions, the complete description of their phase portraits, and a Hamiltonian structure relative to which they are completely integrable (see, e.g., 4).

The book under review deals mainly with optimization problems involving equality constraints with a special structure. Roughly speaking, one can say that the manifolds defined by equality constraints have a structure of a homogeneous space. There are many interesting problems of this type. For example, the set of symmetric matrices with a fixed spectrum or the set of matrices with fixed singular values possess natural structures of homogeneous spaces. Various matrix eigenvalue problems can be formulated as optimization problems on homogeneous spaces described above (see Chapter 1 and Chapter 3 of the book). Many optimization problems on homogeneous manifolds have a very important property that the corresponding gradient flow (under the appropriate choice of the metric) can be written down explicitly (without numerically expensive projection operations) in the so-called double-bracket form discovered by R. W. Brockett [3]. Moreover, the numerical integration of the double-bracket equation can be performed with the essential use of the homogeneous structure (see Chapter 2 of the book). Double-bracket equations play an even more universal role. Many completely integrable Hamiltonian systems that show a gradient-like behavior on common level surfaces of their integrals admit a Lax representation in this form [1], [5], [6].

The realization theory of linear control systems provides a very natural description of manifolds of transfer functions as homogeneous spaces. Several control problems (construction of balanced realizations, sensitivity optimization) are considered as optimization problems on homogeneous spaces of transfer functions in Chapters 5–9 of the book. Interesting connections with the theory of plurisubharmonic functions, invariant theory, and semidefinite optimization are established. In this respect we have to mention recent important applications of semidefinite programming to various control problems [2]. In Chapter 4 a rather brief introduction to the interior-point algorithms for solving linear programming problems is considered. The authors basically use a parameterization of a feasible set by a smooth manifold to get rid of inequality constraints. This approach goes back to Ye, Ye, and Zhadan [8]. The qualitative properties...