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

Controlled and Conditioned Invariants in Linear System Theory—G. Basile and G. Marro. (Englewood Cliffs, NJ: Prentice-Hall, 1992). *Reviewed by J. M. Schumacher.*

Here we have a book that presents a full course on linear systems from the state space point of view, starting from the most basic concepts and working up to the delicate reasoning of the geometric approach. The authors are well known as pioneers of that approach; indeed they were the ones who coined the terms 'controlled' and 'conditioned' invariant subspaces for the subspaces that are also known under the more prosaic names of '(A, B)-invariant' and '(C, A)-invariant' subspaces. In contrast to what its title might suggest, the book not only discusses invariant subspaces and their applications, but also provides an introduction to system theory.

The term 'controlled and conditioned invariance' first appeared in the title of a 1968 University of California at Berkeley College of Engineering report by Basile and Marro, which later appeared as a paper in the *Journal of Optimization Theory and Applications* [1]. In the same period, Wonham and Morse discovered at NASA the utility of controlled invariant subspaces for the decoupling problem and wrote their paper for the *SIAM Journal on Control and Optimization* [2], which featured in its title the term 'geometric approach' that came to describe a whole field of research. While Wonham and Morse were motivated by attempts to generalize the pole-placement theorem and by connections with the decoupling problem [3], Basile and Marro record in [4] their indebtedness to in particular the Soviet literature of the early 1960s [5]–[7]. The geometric theory developed quickly in the 1970s, with Wonham's book [8] serving as the standard reference, and matured in the 1980s. The theory has become a standard tool, in particular, for the analysis of 'singular' situations. As such it plays its own role in H_∞ theory; see for instance [9].

Unlike Wonham's book in its time, the present volume does not aim at giving an exhaustive treatment of the geometric theory. The idea of 'almost invariance' introduced by J. C. Willems [10] is entirely lacking from the book, and no mention is made of the specific meaning of controlled and conditioned invariant subspaces in the context of modeling [11]. Rather, the book by Basile and Marro gently introduces the reader to linear systems in general and to the geometric theory in particular and carefully discusses a number of applications in the control area. The text is therefore suitable for classroom use, and, in fact, the book was developed from courses given by the authors in Bologna and Gainesville.

The first two chapters provide a general introduction to system theory. Although the emphasis is on linear systems, the authors do not simply plunge in with the equations $\dot{x}(t) = Ax(t) + Bu(t), y(t) = Cx(t) + Du(t)$, but make a serious attempt to say in general terms what a 'system' is. Axiomatics is a sensitive and difficult subject; the definitions that Basile and Marro propose are quite traditional and, therefore, almost orthogonal to the framework that has been put forward in recent years by J. C. Willems. Whatever may be said of these differences, the first chapter provides a variety of examples that should enable readers to form their own picture of the subject, independently of the precise formulation of the definitions. In particular, the authors include a discussion of finite-state automata and also pose a number of design problems in this context.

Chapter 2 of the book then concentrates on linear systems. The usual subjects are treated, including free-state evolution, forced-state evolution, a realization algorithm, stability, and controllability and observability. The authors refrain from using the Laplace transform; rather, they consider the transfer function as a convenient shorthand for higher-order differential equations in inputs and outputs. Although they do in this way introduce input–output representations (which are also used later on), at the same time they emphasize their *tenet* that the state-space representation is more convenient for engineering purposes, referring to the capability of the state space description to include nonlinearities and to keep track of parameter changes.

In Chapter 3, the development of the geometric approach begins with a discussion of invariant subspaces in general, followed by a first application of the invariance idea to controllability and observability. The Kalman canonical decomposition is derived geometrically, which gives an excellent example of the way that geometric arguments may replace matrix manipulations. The multivariable pole assignment theorem is proven using a realization in canonical form. The chapter also includes a section on geometric aspects of optimal control,

The reviewer is with the Centrum voor Wiskunde en Informatica, Amsterdam, The Netherlands and the Department of Economics, Tilburg University, Tilburg, The Netherlaands.

IEEE Log Number 9214728.

which has a version of the Pontryagin maximum principle for linear time-varying systems and a treatment of the linear-quadratic problem.

Controlled and conditioned invariant subspaces make their appearance in Chapter 4. They are defined in algebraic terms, and the dynamic characterizations are then immediately given as theorems. Next, 'self-bounded' controlled invariant subspaces are introduced; these are an innovation of the 1980s [12] and can be used elegantly to describe the freedom one has in pole assignment under an invariance constraint. As a first application, the disturbance decoupling problem is treated; this is a classical route that was also followed in Wonham's book. Next, unknown-input reconstructibility and invertibility are discussed. Unknown-input reconstructibility was one of the first motivations of the geometric theory [13] and is important for instance in connection with fault diagnosis.

Chapter 5 is called "*The Geometric Approach: Synthesis,*" and its subject is synthesis by dynamic output feedback. Necessary and sufficient conditions are given for the solvability of a number of design problems, including dynamic disturbance localization, the regulator problem, and the noninteracting control problem. On the latter topic the authors use their treatment in [14], which is less general than the one in the text by Wonham but is easier to understand. This chapter puts much emphasis on the relation between the lattice diagrams of the geometric approach on the one hand and system zeros on the other.

Chapter 6 is concerned with robustness aspects, in particular for the regulator problem (without disturbance rejection). The internal model principle is discussed, and then the authors proceed to the construction of robust regulators using replicas of the exosystem. This construction is due to Francis and Wonham [15]–[16], but here the motivation is different and is essentially based on incorporation of the robustness requirements by changing the model. The authors also give a somewhat tentative treatment of robust regulator design by zero placement and finally discuss what they call hyper-robust problems: these can be seen as continuous gain scheduling problems. In the whole chapter, the uncertainty model is parametric and no use is made of H_∞ techniques.

The book concludes with two appendices, together almost 100 pages long, providing mathematical and computational background. The Matlab routines for subspace computations that are listed in the book are also provided on a diskette that is included with the volume.

The book has been carefully produced, and, in particular, the line drawings are beautifully done. In contrast with some of their previous work, the authors have adopted a notation that is similar to the one used in Wonham's book; this is not essential, but it does facilitate reading for those of us who are used to $\mathcal{V}^*$. The book is well written, although from time to time the choice of words attests to the Romanic background of the authors. In many places, the text shows the enthusiasm of the authors for the beauty of their subject, and that makes the book a pleasure to read. Because of its avoidance of any use of complex function theory, the book might be used to reach audiences which would not easily accept many of the more standard control engineering textbooks; for instance, students of computer science might well benefit from being taught parts of the book by Basile and Marro.

References

[1] G. Basile and G. Marro, "Controlled and conditioned invariant subspaces in linear system theory," *J. Optimiz. Theory Appl.*, vol. 3, pp. 306–315, 1969.

[2] W. M. Wonham and A. S. Morse, "Decoupling and pole assignment in linear multivariable systems: A geometric approach," *SIAM J. Contr. Optimiz.*, vol. 8, pp. 1–18, 1970.

[3] W. M. Wonham, "Response upon receiving award," *IEEE Contr. Sys. Mag.*, vol. 8, p. 96, 1988.

[4] G. Basile and G. Marro, "L'invarianza rispetto ai disturbi studiata nello spazio degli stati," in *Rendiconti della LXX Riunione Annuale AEI*, 1969, paper 1.4.01.

[5] B. N. Petrov, "The invariance principle and the conditions for its application during the calculation of linear and nonlinear systems," in *Proc. 1st Int. Congrss. IFAC*, 1961, pp. 117–125.

[6] V. S. Kulebakin, "The theory of invariance of regulating and control systems," in *Proc. 1st Int. Congrss. IFAC*, 1961, pp. 106–116.

[7] L. I. Rozonoer, "A variational approach to the problem of invariance," *Automatika i Telemekhanika*, vol. 24, pp. 680–691, 793–800, 1963.

[8] W. M. Wonham, *Linear Multivariable Control: A Geometric Approach*. New York: Springer-Verlag, 2nd ed., 1979.

[9] A. A. Stoorvogel, *The H_∞ Control Problem: A State Space Approach*. Englewood Cliffs, NJ: Prentice-Hall, 1992.

[10] J. C. Willems, "Almost A(mod B)-invariant subspaces," *Astérisque*, vol. 75–76, pp. 239–248, 1980.

[11] J. M. Schumacher, "Linear system representations," in *Three Decades of Mathematical System Theory. A Collection of Surveys at the Occasion of the 50th Birthday of Jan C. Willems* (H. Nijmeijer and J. M. Schumacher, Eds.), (Lect. Notes Contr. Inform. Sci. 135), Berlin: Springer-Verlag, 1989, pp. 382–408.

[12] G. Basile and G. Marro, "Self-bounded controlled invariant subspaces: A straightforward approach to constrained controllability," *J. Optimiz. Theory Appl.*, vol. 38, pp. 71–81, 1982.

[13] ——, "On the observability of linear, time-invariant systems with unknown inputs," *J. Optimiz. Theory Appl.*, vol. 3, pp. 410–415, 1969.

[14] ——, "A state space approach to noninteracting controls," *Ricerche di Automatica*, vol. 1, pp. 68–77, 1970.

[15] B. A. Francis and W. M. Wonham, "The internal model principle for linear multivariable regulators," *Appl. Math. Optimiz.*, vol. 2, pp. 170–194, 1975.

[16] B. A. Francis, "The linear multivariable regulator problem," *SIAM J. Contr.*, vol. 15, pp. 486–505, 1977.

0018-9286/94$04.00 © 1994 IEEE