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Book review:

LINEAR SYSTEMS

by

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There exist many good books on linear systems. I wish to mention here only some of them: L.A. Zadeh and C.A. Desoer, *Linear System Theory*, 1963; W.A. Woolrich, *Linear Multivariable Systems*, 1974; W.M. Wonham, *Linear Multivariable Control*, 1979; T. Kailath, *Linear Systems*, 1980; R.A. DeCarlo, *Linear Systems*, 1989; K.Ogata, *Modern Control Engineering*, 1997; C.T. Chen, *Linear System Theory and Design*, 1999; S.H. Zak, *Systems and Control*, 2003. Among these volumes the book by P.J. Antsaklis and A.M. Michel occupies a special place. It is an interesting and original introduction to modern control systems theory. It contains also many interesting problems from advanced systems theory. According to the authors the primary aim of the book is the following: "The primary aim of this text is to provide an understanding of (...) fundamentals by emphasizing mathematical descriptions of systems and their properties. Our goal was to clearly present the fundamental concepts of system theory in a self-contained text". The goal was reached and performed by the authors in an excellent way.

The book consist of a preface, seven chapters and an appendix.

Chapter 1 is devoted to mathematical descriptions of linear continuous-time and discrete-time

finite-dimensional systems. The chapter starts with preliminaries from the calculus, analysis and linear algebra. Next, the initial-value problems, determined by systems of first-order nonlinear ordinary differential equations are introduced. Conditions for the existence and uniqueness of solutions are established. The linearization of nonlinear systems, the solutions of linear state equations, the method of successive approximation, the response of a linear system to an input, given initial states, are discussed. The internal and external behavior of a system input-output descriptions of linear systems, the convolution integral for continuous-time system and the convolution sum for discrete-time systems are also presented.

In Chapter 2 the response of linear system is addressed. First, some mathematical background from linear algebra and matrix theory are given. Linear subspaces of vector spaces, linear independence of a set of vectors, bases of vectors spaces, linear transformations defined on vectors spaces, the representations of such transformations by matrices, some of the properties of matrices and determinations of matrices, solutions of linear algebraic equations, the equivalence and similarity of matrices, eigenvalues and eigenvectors, the direct sum of linear subspaces, canonical forms of matrices, minimal polynomials of matrices, nilpotent operators and the Jordan canonical form are discussed. Then, the authors consider the systems of linear ordinary differential equations, the fundamental matrix, the state transition matrix, the stability of an equilibrium, linear periodic systems, the state equations and input-output description of continuous-time and discrete-time systems, transfer functions, the equivalence of internal representations and sampled-data systems.

Chapter 3 consists of two parts. In Part 1 the concepts of state reachability, controllability, observability and constructibility for continuous-time and discrete-time, time-varying and time-invariant systems are introduced. In Part 2 special forms for state-space representations for controllable or uncontrollable and observable or unobservable continuous-time and discrete-time systems are presented. The Smith-McMillan form of a transfer matrix and the poles and zeros of a system are given. Polynomial matrix fractional descriptions of transfer matrices by the structure theorem are also introduced and zero directions and pole-zero cancellations are studied.

In Chapter 4 the concept of feedback is introduced and the problem of pole (eigenvalue) assignment by state-feedback is discussed. It is shown that it is possible to arbitrarily assign all closed-loop poles by linear static state-feedback if and only if the open-loop system is completely controllable . The linear quadratic regulator problem for continuous-time and discrete-time system is considered. State observers that asymptotically estimate the states form input and output measurements over time are also studied. State feedback static controllers and state dynamic observers are combined to form dynamical output feedback controllers. Such controllers are studied using both the state-space and transfer matrix descriptions.

The theory of realizations for continuous-time and discrete-time system is introduced in Chapter 5. State-space realizations of impulse and pulse responses for time-varying and time-invariant systems and of transfer functions (of time-invariant system) are discussed. The existence of state-space realizations for both time-varying and time-invariant system is considered. Minimal (irreducible) realizations are discussed for time-invariant system. It is shown that a state-space realization is minimal if and only if it is both controllable and observable and the order of minimal realization can be determined directly from a given transfer matrix by use of its pole polynomial of the transfer matrix that determines its McMillan degree. It is also shown that in any minimal realization the pole polynomial of the transfer matrix is the characteristic polynomial of the matrix A. A number of algorithms for obtaining realizations in controller and observer form are presented.

Chapter 6 is devoted to the stability theory of linear and nonlinear finite-dimensional continuous-time and discrete-time systems. This chapter consists of three parts. In Part 1 some background material form linear algebra is presented and the Lyapunov stability of an equilibrium is addressed. The concept of equilibrium of dynamical systems described by system of first-order ordinary differential equations are introduced and definitions of various types of stability in the sense of Lyapunov are given. Conditions for the Lyapunov stability and instability for linear system are established. The second method of Lyapunov is introduced and necessary and sufficient conditions for various Lyapunov stability types of an equilibrium for linear system are presented. Then, in Part 2, the necessary and sufficient conditions for the input-output stability of continuous-time, linear time-varying and time-invariant systems are established. A connection between the bounded input / bounded output stability and the exponential stability of linear system is given. In part 3 analogous stability results for discrete-time, time-invariant systems are presented.

In Chapter 7 the polynomial matrix descriptions (PMD) and matrix fractional descriptions (MFD) are used to study the controllability, observability and stability of interconnected linear continuous-time systems. This chapter consist of two parts. In Part 1 the background on polynomial matrices and the Diophantine equation is provided. Equivalence of representations and system properties consisting of subsystems interconnected in parallel, in series and in feedback configurations are investigated. Special forms for polynomial matrices, polynomial matrices in column reduced, triangular Hermite and Smith form are defined and algorithms to, obtain such forms are given. Coprimeness of polynomial matrices and the controllability and observability of PMDs are studied. In Part 2, feedback control systems are studied using PMDs and MFDs with emphasis on stabilizing controllers. All stabilizing controllers are parameterized using PMDs. The complete theory of parameterizing all stabilizing feedback controllers is developed. The model matching problem, the diagonal decoupling problem and the static decoupling problem are also discussed.

In the Appendix some computational methods for solving linear algebraic equations, singular-values, singular-value decompositions, polynomial matrix and rational matrix equations based on polynomial matrix interpolation are presented.

At the end of each chapter basic references are given and many interesting examples are included to clarify the material of the chapter. The exercises introduce additional concepts and results giving additional insight in the material.

This is an interesting, original and excellent textbook. It can be recommended for first year graduate students and advanced undergraduates in electronic engineering, electronics and mechatronics, who are interested in control system and signal processing.

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Panos J. Antsaklis, Anthony N. Michel, *Linear Systems.* Birkhäuser Verlag, Basel- Boston- Berlin, 2006, XVIII+670 pages. ISBN 0-8176-4434-2. Price (hardcover): 72 EUR.