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Estimation and Control of Systems*

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AT THE END of the 1950s classical control theory techniques had reached a certain mature stage. Everyone working in electrical engineering has come in touch with names like Nyquist, Bode, Wiener, Kolmogorov, McMillan etc. and has heard of notions like gain and phase margin, root locus, feedback stability and so on. All these names and concepts have had direct appeal to linear system theory.

In the early 1960s an extremely important breakthrough was made by Kalman and later by many other scholars. This revolution, so to speak, centres around the concept of the state of a linear system. Some of the most striking achievements of the introduction of the state concept are the complete solution of the LQ and LQG problems, and the development of a more or less complete linear realization theory, allowing the construction of a minimal state space system for a given transfer matrix. Certainly there are other more recent advantages in the state space theory of linear systems, e.g. the geometric approach advocated by Wonham and others, or contributions to identification and adaptive control theory.

The present book under review, *Estimation and Control of Systems*, is intended as a textbook for students with a background in science or engineering and deals with two main topics, namely control by state feedback and estimation theory for state space models. A sort of implicit assumption is familiarity with the tenets of classical control theory. Next a short description of the contents of the book is given. The first chapter contains a very short introduction of the material of the book. Chapter 2 is concerned with probability and estimation theory. It contains a discussion on random variables, functions of random variables, limit theorems and several basic estimation methods for random and non-random variables. In Chapter 3 a treatment of characterizations and properties of stochastic processes is given. After these two preliminary chapters on probability and statistics the author describes in Chapter 4 the basic tenets of system theory encompassing notions like controllability, observability and stability. Then, in Chapter 5 modal control of linear dynamic systems is discussed. Characteristic topics such as pole placement and (reduced order) observer design are treated in some detail, as before both in continuous and discrete time. Chapter 6 is devoted to optimal control of linear systems. Using the ingredients of calculus of variations, the maximum principle is described for and applied to the standard optimal control problems, e.g. minimum time problems and minimum cost problems with or without control variable constraints, again in continuous and discrete time. Next, in Chapter 7 the author returns to the uncertainty in system theory. First several estimation problems (parameter estimation and the estimation of random variables) are treated. The second part of this chapter contains a discussion of elementary filtering and smoothing problems. In the last chapter of the book a short introduction of dynamic programming as a system optimization technique is given. The book ends with four appendices, three dealing with the required preliminaries on matrix theory, optimization theory and the theory of linear differential equations and the last a short comparison of modern and classical control theory. Before ending this summary of the contents of *Estimation and Control of Systems* it is worth noting a fact that will be much appreciated by many readers. In each chapter some characteristic examples of the theory are given and each chapter contains an overwhelming list of (sometimes simple) exercises.

An author writing a textbook to be used in engineering departments is faced with several difficult decisions. First of all — and this is true for almost all textbooks — a principal question is, which material should be included and, maybe more important, what should be omitted? Often this has implications on the inclusion or exclusion of the modern (newest) developments in the field. Elbert is not striving to treat the newest directions of research, although some recent advances are included in the references at the end of each chapter. In this respect it is an interesting fact that most of the topics treated by Elbert are also discussed in Kwakernaak and Sivan's book, which dates back to 1972. In some instances the inclusion of relevant material would have been particularly useful. For example by using the result of Heymann (1968) the pole placement problem for a multi-input controllable system can be reduced to that of a single-input controllable system.

A second difficulty in writing a textbook like *Estimation and Control of Systems* is how much mathematics is really required in the theoretical developments. Obviously, and fortunately, Elbert did not opt for the definition–theorem–proof format (in European mathematics sometimes referred to as the "Bourbaki" style). However being trained as a mathematician, I feel that the avoidance of such a formal style may produce imprecise statements or, even worse, serious mistakes in the text. For example on p. 110 the following definition of observability is given: "A system is said to be observable over the interval (t_1, t_2) if the system state at time t_2 can be determined from observations of the output during the interval (t_1, t_2)", not including knowledge of the input function on this time interval. In the treatment of the regulator problem no emphasis is made on the solvability requirements for the algebraic Riccati equation. A similar remark could be made on the Kalman filter equations in Chapter 7, a precise treatment of which, in discrete time, can be found in Anderson and Moore (1979). The construction of the generalized "control canonical form" as given in Chapter 5 is incorrect because the "control invariants" as introduced here, are by no means invariant under state feedback (and state space transformations); a correct treatment of control canonical forms is given in Brunovsky (1970). In treating the maximum principle in optimal control it is obvious that a necessary but in general not sufficient condition for optimality is that the unrestricted control variable should satisfy the condition that the partial derivative of the Hamiltonian with respect to the control vanishes. Unfortunately, there are other statements of this type in this otherwise readable and well written text.

A third criticism concerns the notion of state as given in the book. As noted in the first paragraph of this review, it was in the early 1960s that the concept of state was introduced in its full power in control theory. I have the feeling that the author did not use this state concept in its full generality. In various places and in particular in the worked examples the author often uses physical states as illustrations of the state space mechanism. In its full generality the coordinatization of the state space arising in the time-domain realization of a prescribed transfer matrix has no physical meaning. Of course one could be content with Elbert's explanation, and I think most people in electrical engineering are, but I still feel that the full power of state space methods in control theory has not been used in this book.

* *Estimation and Control of Systems* by Theodore F. Elbert, Published by Van Nostrand Reinhold, New York (1984), 649 pp., US $47.05.

Altogether this book, which is very well written, is not too different from several others published in the same area. The explanation of state space concepts is done in a way typical in engineering and especially in electrical engineering. Those who want a more detailed theoretical (mathematical) exposure better consult other textbooks, but they may take the opportunity to read Elbert's view on the comparison of modern and classical control theory (Appendix D). As noted earlier the author should be complimented on producing an enormous list of good/simple examples and exercises. Maybe they will find their way into classrooms. The rest is just an addition to the technical literature.

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About the reviewer

Henk Nijmeijer received both his university degree and doctorate in mathematics from the University of Groningen, Groningen, The Netherlands in 1979 and 1983, respectively. After spending three years at the Center for Mathematics and Computer Science (CWI) in Amsterdam, he took a research/teaching position at the Department of Applied Mathematics of the Twente University of Technology, Enschede, The Netherlands in 1983. His main research interest lies in the area of nonlinear and linear geometric control theory.

Safety Systems Reliability

A. E. Green

Reviewer: S. HUMBLE
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RELIABILITY and safety are often described as two sides of the same coin. The determination of the safety level of a plant, however, requires more than just a knowledge of the reliability of the system. One must also consider the likely frequency of accidents, whether man-made or natural, and in many plants the probability of the accident occurring will be a combination of some abnormal event and of the failure (i.e. unreliability) of the particular preventative system designed to protect the plant at such times. Moreover, one must then try to estimate the risk caused by such accidents which is usually defined as the combination of the probability of such an event, together with its likely consequences.

This definition of safety, and its relationship to, and differences from, normal reliability engineering are very clearly demonstrated in this book. In a clear and straightforward way, it takes the reader through all the major techniques currently being used to design and assess safety system reliability. The text is written from the author's knowledge of the nuclear power industry. However, the techniques are equally valid for many other types of plant. Moreover, the examples chosen are all successfully aimed at bringing home the salient points and provide a richness of detail which is often lacking in texts of this type.

The author starts with an historical introduction to the subject, followed by some fairly standard sections on probability and reliability theory. However, even here the author stresses the importance of the human factor, which is so often neglected in other texts. In subsequent chapters the author concentrates on the estimation and monitoring of high reliability systems. Here again, unlike many texts there is a necessary change of emphasis. In view of the very high reliabilities required, and hence the rarity of failures, there is a most useful discussion on how one goes about estimating such reliabilities using subjective data as well as reliability data banks.

Not only is his book liberally sprinkled with examples from his own experiences, Dr Green also includes further illustrations in appendices contributed by Mme A. Carnino and Dr V. Joksimovich which add significantly to the practical flavour of the book. Indeed, it is very much a practical book for the practitioner. Given the limitation of the length of the text, I believe the author should be congratulated on producing a very readable and informative guide to a very difficult subject area. I would recommend it as a good introduction, although I would warn the reader that it should not be the only text he reads on the subject.

Safety Systems Reliability by A. E. Green. Published by John Wiley, Chichester (1983), US $38.15.

About the reviewer

Professor Humble obtained his bachelor's degree and Ph.D. from the University of Durham. He has held teaching research posts at Trinity College, Dublin; University of Colorado; Science Research Council in England; CERN, Geneva; Sheffield City Polytechnic and The Royal Military College of Science, where he is now Professor of Operational Research and Statistics and Chairman of The School of Management and Mathematics. His practical interests lie in systems assessment and reliability engineering.

Control System Synthesis: A Factorization Approach

M. Vidyasagar

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THE BASIC problem in recent control system synthesis has been: given a linear time-invariant plant, P (not necessarily stable) and a set of performance specifications, design a compensator, C, such that the resulting plant–compensator feedback system meets the latter. An explosion of results concerning this problem has been generated in the last decade by well known researchers, among which the reviewer cites Youla, Kucera, Desoer, Saeks, Vidyasagar, Francis, Zames and Doyle, to name but a few. The strategy developed has been: (1) find *necessary and sufficient conditions* such that the plant–compensator feedback system has certain *desirable features* such as closed loop stability, tracking of a reference signal, rejection of disturbances etc.; (2) *parametrize all compensators* such that the feedback system meets such feature(s) in such a way that the parametrization is *affine* in one or two (stable) free parameters; (3) select the parameter(s) to obtain a compensator such that the closed loop behaviour is

Control System Synthesis: A Factorization Approach by M. Vidyasagar. Published by MIT Press, Cambridge, Massachusetts (1980). US $47.25.