CONTROL AND DYNAMIC SYSTEMS

Advances in Theory and Applications

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PREFACE

The ninth volume of "Advances in Control Systems" continues the purpose of this serial publication in bringing together diverse information on important progress in the field of control and systems theory and applications as achieved and presented by leading contributors. The growing emphasis on application to large scale systems and decision making continues to be made evident by this volume.

In fact, in order to emphasize this, beginning with this volume, the series will henceforth be published under the new title "Control and Dynamic Systems: Advances in Theory and Applications." Indeed, it is interesting to reflect briefly here on the metamorphosis of the field over the past few decades.

Although control systems have been with us since the beginning of mankind, effective analysis and synthesis techniques really began to evolve in the 1940's. During that decade the system model was simple and typically second order, such as a radar antenna or the single axis of an aircraft or simple missile or other similar simple examples. In the 1950's the models became somewhat more complex, including examples such as process control systems, ballistic missiles, and other similarly complex systems. In addition, techniques for nonlinear system analysis and synthesis were just evolving. In the 1960's state space techniques became well established and supported the developments in optimization techniques such as dynamic programming, the Pontryagin Maximum Principle, and other optimization techniques and methods as well as Kalman filtering and the flood of ideas and results it generated. Now the system models became substantially more complex, with the result that here in the early 1970's we have seen control techniques applied to large scale economic systems, medical systems, large scale urban problems, and many other complex systems models.

The potential for the future is, of course, very substantial. Indeed, it is almost appropriate to use the terms control or dynamic decision making interchangeably, and in thinking of applications to cover the gamut from simplistic system models to the most complex of systems. By the same token this carries with it the clear requirement for modeling techniques, particularly for the more complex systems, and, among a whole host of other modeling and system parameter identification issues, the question of developing simpler but meaningful representations or models of very complex systems in order that the process of system analysis, synthesis, and control or dynamic decision making may proceed in a meaningful way. The future is clearly exciting, and offers many opportunities for the development of significant results, particularly in the applied areas. Future volumes in this series will reflect these significant trends.

With this volume the conversion to a camera copy format is initiated in order to substantially reduce the lead time from completion of manuscripts to publication of the volume, and incidentally a reduction of cost per printed page will result.

To begin the description of the present volume, a contribution by L. M. Novak treats the important issue of optimal observer techniques for linear discrete time systems. Since the early important work of D. G. Luenberger on observer theory and techniques there have been a wide diversity of publications on this subject. An overview of the status of this field is presented in this contribution, and numerous basic new results are presented. Extensive computer simulation studies are presented which rather clearly indicate the significance of the observer approach to filtering problems.

Two to three decades ago the application of control theory techniques, such as they were then, were to very simple, almost elemental systems by today's standards. The trend toward the application of control systems techniques to large scale systems problems is well exemplified in the contribution by D. L. Erickson and F. E. Norton, in which they present the application of modern control theory to problems in the optimal control of the national economy. This contribution continues in the same spirit of the contribution by L. F. Buchanan and F. E. Norton in the previous volume on optimal control in the national economy, and considers extended problems in this regard. It is rather interesting to note that the primary contribution of this year's recipient of the Nobel Prize Award in Economics was based on his recognition that it was absolutely essential to gather fundamental economic data in the 1920's to 1930's for decision making. The world was slipping into the great depression of 1929 and did not have the data essential to fully realize this. Since that time and in the last decade, in particular, substantial efforts have been devoted to developing improved and more comprehensively descriptive models of the national economy. Indeed, a rather comprehensive analysis of the effectiveness of these model building efforts for the national economy appeared in a rather extensive article in the August 23, 1972 issue of the *Wall Street Journal.* The fact is that a fruitful area for research for control theory with a view toward the development of substantive decision making tools on the national as well as international scene remains ahead in this area. The contribution by D. L. Erickson and F. E. Norton may perhaps help to some substantive extent in this regard by illuminating a number of important issues.

The contribution by A. Miele, A. V. Levy, R. R. Iyer, and K. H. Well presents a new and rather powerful modified quasilinearization method for the solution of mathematical programming and optimal control problems. The search for methods of greater power for the solution of system optimization problems will no doubt continue indefinitely. This contribution represents a potentially significant extension in the capability of one of the several basic algorithmic approaches for obtaining answers to system optimization problems, and could very well find very broad acceptance in the utilization of this technique for the solution of these problems.

Ever since the classic work of R. A. Howard in his book "Dynamic Programming and Markov Processes," published in 1960 and updated in his two-volume comprehensive treatise "Dynamic Probabilistic Systems" published in 1971, the question of decision making in systems ranging from small to large scale systems wherein there are important basic unknowns in the system model, such as the transition probabilities, remains as a substantive one in effectively addressing these important issues. The contribution by W. R. Osgood and C. T. Leondes presents a number of basic results for dealing with these extensions in this broad problem area and illustrates their utility through application to a number of illustrative examples.

Among the several significant advantages of feedback control systems is the reduction in the deleterious effect of system parameter variations on the performance of the control system. The past decade has seen a resurgence in the exploration of these issues through such techniques as system sensitivity analysis, and optimization formulations have been presented which include some suitable measure of system sensitivity in the performance index. The contribution by R. N. Crane and A. R. Stubberud on closed loop formulations of optimal control problems for minimum sensitivity reviews many of the important results developed to date in this field and develops numerous new and fundamental results including the development of a new formulation of the trajectory sensitivity problem which is applicable to general nonlinear systems. The utility of the various results developed are illustrated through application to several examples.

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Optimal Observer Techniques for Linear Discrete Time Systems[1]

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I. FORMULATION OF THE STATE ESTIMATION PROBLEM

A. Abstract and Introduction

This chapter investigates the idea of using Luenberger's minimal-order observer as an alternate to the Kalman filter for obtaining state estimates in linear discrete-time stochastic systems. One of the major results presented in the chapter is the development of the general solution to the problem of constructing an optimal minimal-order observer for linear discrete-time stochastic systems where optimality is in the mean-square sense. The approach taken in the development which follows leads to a completely unified theory for the design of optimal minimum-order observers and is applicable to both time-varying and time-invariant linear discrete systems.

The basic solution to the problem is first obtained for that class of systems having white noise disturbance inputs. The solution is based on a special linear transformation which transforms the given time-varying discrete-time state equations into an equivalent state space which is extremely convenient from the standpoint of observer design. Design of the observer is based on a unique observer configuration containing an arbitrary gain matrix, K_i, which is chosen to minimize the mean-square estimation error at each instant "i". This gain matrix is computed recursively using algorithms similar to the Kalman filter algorithms. The solution obtained is optimal at each instant "i" and therefore is optimal both during the transient period and in the steady-state. In the special case of no measurement noise, it is shown that the observer estimation errors are identical with those of the corresponding Kalman filter. When measurement noise is not excessive, estimation errors comparable with a Kalman