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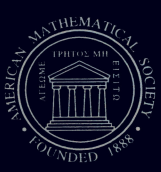
Volume 157

Control of Systems with Aftereffect

V. B. Kolmanovskiĭ
L. E. Shaĭkhet



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V. B. Kolmanovskiĭ
L. E. Shaĭkhet

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Е. А. АНДРЕЕВА, В. Б. КОЛМАНОВСКИЙ, Л. Е. ШАЙХЕТ

УПРАВЛЕНИЕ СИСТЕМАМИ С ПОСЛЕДЕЙСТВИЕМ

МОСКВА «НАУКА»
ГЛАВНАЯ РЕДАКЦИЯ
ФИЗИКО-МАТЕМАТИЧЕСКОЙ ЛИТЕРАТУРЫ
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ABSTRACT. Deterministic and stochastic control systems with aftereffect are considered. Necessary and sufficient conditions for the optimality of such systems are obtained. Various methods for the construction of exact and approximate solutions of optimal control problems are suggested. Problems of adaptive control for systems with aftereffect are analyzed. Numerous applications are described.

The book can be used by researchers, engineers, and graduate students working in optimal control theory and various applications.

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Contents

Preface ix

Chapter 1. Elements of the theory of systems with aftereffect 1
§1.1. Differential equations with aftereffect 1
§1.2. Modeling systems with aftereffect 8
§1.3. Statements of problems of control and observation 18

Chapter 2. The dynamic programming method 21
§2.1. The Bellman equation 21
§2.2. A linear-quadratic problem 23
§2.3. Bilinear controlled systems 29
§2.4. Stabilization problems 36

Chapter 3. Optimality conditions for deterministic systems with aftereffect 51
§3.1. Conditions for optimality of systems with constant lag in the phase variable 51
§3.2. Linear time-optimal problem 57
§3.3. The optimal control problem with unfixed time 58
§3.4. The linear optimal control problem with fixed time 59
§3.5. Optimal control of systems with variable lag in state 61
§3.6. Optimal control of systems with lag in control 63
§3.7. The optimal control problem for a system of integro-differential equations with aftereffect 65
§3.8. Approximate methods for solving optimal control problems with aftereffect 69
§3.9. Conditions for optimality of neutral-type systems 73
§3.10. The optimal control problem for a system with distributed aftereffect 80

Chapter 4. Investigation of self-adjusting systems with reference model 83
§4.1. The stability of self-adjusting systems with reference model 83
§4.2. The identification of systems using adaptive models 93
§4.3. The stability of self-adjusting lag systems 102
§4.4. The investigation of transient processes in self-adjusting systems 108
§4.5. The synthesis of aperiodic self-adjusting systems 113

Chapter 5. Optimal control of stochastic systems 119
§5.1. The synthesis of optimal control 119
§5.2. Linear systems with quadratic performance functional 121

§5.3. An approximate synthesis of optimal control 128
§5.4. Quasilinear systems 132
§5.5. Systems with noise-contaminated control 142
§5.6. Examples 146
§5.7. Systems with Poisson perturbation in the controlling device 152
§5.8. Numerical solution of the time-optimal control problem 159
§5.9. Numerical solution of the problem of maximization of the probability of sojourn of a system in a given domain 168

Chapter 6. Optimal control of systems defined by stochastic integro-functional equations 179
§6.1. Statement of the problem 179
§6.2. Stochastic integro-functional equations 180
§6.3. A necessary condition for optimality of noise-contaminated control 184
§6.4. A necessary condition for optimality of control without noise 190
§6.5. A linear-quadratic problem 196
§6.6. Examples 203
§6.7. Quasilinear systems 229

Chapter 7. Optimal estimation 243
§7.1. The filtering problem 243
§7.2. The fundamental filtering equation 246
§7.3. Forecasting and interpolation 252
§7.4. Filtration of processes described by integral equations 253
§7.5. Examples 261

Chapter 8. Optimal control with incomplete data 285
§8.1. Partially observable Volterra processes 285
§8.2. Stochastic systems with unknown parameter 300
§8.3. Adaptive control 308
§8.4. Examples 311

Bibliography 323

Preface

The study of various natural and social phenomena shows that the future development of many processes depends not only on their present state but is essentially influenced by their previous history. Such processes can be described mathematically using the machinery of equations with aftereffect.

This explains the rapid intensification of theoretical investigations of qualitative properties of systems with aftereffect we have seen in recent years. These investigations have been carried out in various directions, among which optimal control occupies a prominent place. The results obtained thus far find wide application in automatic control, mechanics, technology, economics, medicine, biology, and other areas of human activity. However, the analysis of systems with aftereffect is fraught with difficulties which result, for example, in the absence of exact analytic solutions except in very special cases. What is more, along with difficulties common with finite-dimensional problems, controlled systems with aftereffect present their own challenges stemming, first of all, from the fact that their phase space is usually infinite-dimensional. Attempts to surmount these difficulties have resulted in a variety of methods for solving control problems oriented toward specific classes of systems with aftereffect.

In this book, consisting of eight chapters, the main methods of exact and approximate solution of problems of optimal control and estimation for deterministic and stochastic systems with aftereffect are expounded.

Chapter 1 is the introduction. It contains numerous examples of phenomena from mechanics, medicine, ecology, and automatic control that can be described by equations with aftereffect. Further, essentials of the theory of these equations to be used in the subsequent chapters are presented. In particular, the fundamental initial problem is stated, a classification of equations with aftereffect is given, the existence and uniqueness theorems for solutions of various types of equations are formulated, and some methods of stability testing for such equations are described. A separate section is devoted to the description of statements of control and observation problems, both in their traditional setting and in the distinctive setting for systems with aftereffect.

Chapter 2 is concerned with the dynamic programming method. The fundamental functional equation, which is used later for the construction of optimal control and for finding the minimal value of the performance criterion, is considered. The linear-quadratic problem is solved for various classes of systems with aftereffect, bilinear controlled systems are investigated, and the stabilization problem is studied.

Chapter 3 presents conditions for optimality in control problems for systems with lag in phase coordinates and control. Linear systems and nonlinear systems

with constant and variable lags are treated separately. Necessary conditions for optimality in the form of the maximum principle are formulated for systems with several constant lags and with variable lag. Sufficient optimality conditions are proved. Various methods for finding approximate solutions for control problems under consideration are described.

Chapter 4 is devoted to the investigation of self-adjusting systems with reference model.

In Chapter 5 a general approach to stochastic problems of optimal control for systems with aftereffect is expounded, and a method is developed for constructing successive approximations to optimal control in quasilinear systems.

In Chapter 6 the problem of finding necessary conditions for the optimality of a control is formulated and the possibility of construction of the optimal control synthesis* for linear-quadratic problems is discussed. An integral equation of the neutral type is introduced, and existence and uniqueness theorems for solutions of these equations are proved. A necessary condition for the optimality of a control is obtained for nonlinear integral equations. Systems with noise-contaminated and noise-free control are analysed separately.

Using necessary conditions of optimality for a linear Volterra equation and quadratic functional, a synthesis of the optimal control is constructed.

These results generalize classic solutions of the linear-quadratic problem for stochastic systems. Methods for calculating optimal control synthesis are illustrated by examples, and an ε-optimal control is constructed for quasilinear systems with aftereffect.

In Chapter 7 the filtering problem is formulated and the Wiener–Hopf equation for an unobservable general Gaussian process is derived, the forecasting and interpolation problems are considered, and a filtering theorem for integral equations is proved.

In Chapter 8 various problems of control with incomplete information about the controlled object are described. The linear-quadratic problem of control of the partially observable solution of the Volterra equation is investigated by two methods: the standard one based on the separation principle and a new one (the method of integral representations), which leads to simpler control and estimation algorithms. A numerical procedure for solving these problems is elaborated. The control problem for systems with unknown parameters under random perturbations is considered, some general statements are formulated for this problem, exact solutions are found, and successive approximations to the optimal control in the quasilinear case are constructed. Two problems of the theory of adaptive control are solved: the problem of adaptive control with reference model and stabilization problem.

Each chapter contains examples illustrating central tenets of the book and their applications to concrete systems.†

The book is mostly based on authors' results obtained between 1970 and 1990. It also contains a number of recent results obtained by other scientists.

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*By *synthesis of a control* we always mean the control constructed from the feedback principle.

†*Editor's note*: Throughout the volume equations have a two number reference. When referencing equations in other chapters, however, a third number precedes the equation number, indicating the chapter in which the equation is located.

The bibliography at the end of the book is far from being complete. It includes only the literature that was used by the authors during their work on this book. But that literature, in its turn, contains extensive bibliographical information on the topic.

The book is intended for scientists and experts in control theory, applied and computational mathematics.

At various stages of work the results included in the book were a subject of fruitful discussion with I. I. Gikhman, M. A. Krasnosel′skiĭ, A. B. Kurzhanskiĭ, R. Sh. Liptser, A. D. Myshkis, Yu. S. Osipov, A. V. Skorokhod, R. Z. Has′minskiĭ, and F. L. Chernous′ko, to whom we express our sincere gratitude. The authors will appreciate receiving any comments and suggestions.

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