Optimization Methods and Applications

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Optimization Methods and Applications

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Dr. Nasir U. AHMED

Contents

Preface	xi
An Appreciation of Professor N.U. Ahmed	xiii
A Publication List of Professor N.U. Ahmed	xvii
Part I OPTIMAL CONTROL	
1 PRACTICAL STABILITY OF IMPULSIVE DELAY DIFFERENTIAL EQUATIONS AND APPLICATIONS TO CONTROL PROBLEMS	3
<i>George Ballinger and Xinzhi Liu</i>	
1 Introduction	4
2 Preliminaries	4
3 Main Results	6
4 Application	10
References	21
2 A REVIEW OF ILL-CONDITIONING AND REGULARIZATION IN OPTIMAL CONTROL COMPUTATION	23
<i>Francis Benyah and Les S. Jennings</i>	
1 Introduction	24
2 Optimal Control Problem Template for MISER3	25
3 Control Parametrization	26
4 State Discretization Methods	27
5 Condition Numbers for Constrained Optimization	30
6 Test Problem 1	32
7 Regularization of Optimal Control Problems	35
8 Test Problem 2: The Container Crane Problem	39
9 Conclusions	40
References	42
3 WORST-CASE OPTIMAL REGULATION OF LINEAR SYSTEMS IN THE PRESENCE OF STRUCTURED PERTURBATIONS	45
<i>Saroj K. Biswas and M. Bala Subrahmanyam</i>	
1 Introduction	46
2 Problem Statement	47
3 Optimal Solution	50

vi OPTIMIZATION METHODS AND APPLICATIONS

4	Computation of Disturbance Rejection Capacity	57
5	Examples	58
6	Conclusions	61
	References	61
4	TRUE PROPORTIONAL NAVIGATION SYSTEM WITH ACCELERATION SATURATION CONSTRAINT	65
	<i>Cheng-Chew Lim and Mingyan Li</i>	
1	Introduction	66
2	System Model	66
3	Saturation Constraint Analysis	68
4	Observability with Saturation Constraint	74
5	Simulation Results	76
6	Conclusions	79
	References	79
5	EVALUATION OF PENALTY FUNCTIONS FOR OPTIMAL CONTROL	81
	<i>Rein Luus, Wichaya Mekarapiruk and Colin Storey</i>	
1	Introduction	82
2	Problem Formulation	82
3	Iterative Dynamic Programming (IDP)	84
4	Numerical Results	86
5	Concluding Remarks	100
	References	102
6	ON THE OPTIMAL CONTROL SYSTEMS WITH MULTIPLE CONTROLLERS	105
	<i>Katsumi Moriwaki</i>	
1	Introduction	106
2	Optimal Regulator and Preliminaries	107
3	LQR Problem with 2 Controllers	109
4	Controllers Decoupling via Internally Balanced State Space Representations	115
5	Numerical Examples and Discussions	118
6	Conclusion	122
	References	123
7	MULTILEVEL OPTIMIZATION OF OPTIMAL CONTROL PROBLEMS	125
	<i>Volker Rehbock</i>	
1	Introduction	126
2	General Problem	128
3	Multilevel Approach	128
4	Implementation	131
5	Numerical Results	133

6	Parallel Implementation	136
7	Conclusions	137
	References	138
8	MODIFIED DIRECT GRADIENT DESCENT CONTROL OF NONLINEAR SYSTEMS	139
	<i>K. Shimizu, S. Ito and K. Otsuka</i>	
1	Introduction	140
2	Direct Gradient Descent Control	140
3	Modified Direct Gradient Descent Control	142
4	Simulation	144
5	Concluding Remarks	146
	References	146
	Appendix: Stability	148
9	COMPUTATION OF FEEDBACK CONTROL FOR INFINITE TIME OPTIMAL CONTROL PROBLEMS	151
	<i>K.H. Wong and G. Peter</i>	
1	Introduction	152
2	Problem Statement	153
3	The Approximation Problem ($P(T)$)	153
4	Synthesizing the Optimal Feedback Control Law for the Approximate Problem ($P(T)$)	154
5	Interpolation using a Cubic Spline Approach on the Fitting Domain $\mathcal{D}_{\hat{T}}$	156
6	Creating an Approximate Problem Using Cubic Spline Feedback Structure on the Domain $\mathcal{D}_{\hat{T}}$	157
7	Properties of Asymptotic Stability of the Optimal Control Feedback Control of the Problem (Q)	158
8	Finite Time Approximation to the Problem (Q)	159
9	A Practical Example	159
	References	163
	Part II OPTIMIZATION METHODS	
10	A HOMOGENIZED CUTTING PLANE METHOD TO SOLVE THE CONVEX FEASIBILITY PROBLEM	167
	<i>E. D. Andersen, J. E. Mitchell, C. Roos and T. Terlaky</i>	
1	Introduction	168
2	Barrier functions and proximity measures	169
3	A column generation method	171
4	Choosing a restart point	175
5	Global convergence	178
6	An implementation	179
7	Computational results	185

8	Conclusions	188
	References	189
11	ALGORITHMS FOR SOME HARD KNAPSACK PROBLEMS	191
	<i>Louis Caccetta and Araya Kulanoot</i>	
1	Introduction	192
2	Preliminaries	195
3	Subset Sum Problem (SSP)	197
4	Strongly Correlated Problem (SCKP)	201
5	Inverse Strongly Correlated Knapsack Problem (ISCKP)	205
6	Bounded Knapsack Problem (BKP)	207
7	Conclusions	214
	References	214
12	NON-STATIC NETWORK OPTIMIZATION PROBLEMS: A SURVEY	219
	<i>X. Cai, D. Sha and C. K. Wong</i>	
1	Introduction	220
2	The Non-Static Network Flow Model	220
3	Non-Static Shortest Path Problems	224
4	Non-Static Maximum Flow Problems	227
5	Non-Static Minimum Cost Flow Problems	230
6	Non-Static Vehicle Routing Problems	233
7	Other Non-Static Network Optimization Problems	236
8	Conclusions	237
	References	238
13	ASYMPTOTIC RATES OF CONVERGENCE OF SQP-TYPE METHODS OF FEASIBLE DIRECTIONS	247
	<i>Michael M. Kostreva and Xibin Chen</i>	
1	Introduction	248
2	Definitions and Propositions	250
3	Asymptotic Rate of Convergence	254
4	Comparison of Convergence Rates	262
5	Conclusions	263
	References	264
14	NONLINEAR LAGRANGIAN METHODS IN CONSTRAINED NONLINEAR OPTIMIZATION	267
	<i>Duan Li and Xiaolin Sun</i>	
1	Introduction	268
2	p -th Power Lagrangian Method	270
3	Minimax-type Lagrangian Function	271
4	Logarithmic-Exponential Lagrangian Function	274

5	Conclusions	276
	References	276
15	PARALLEL ALGORITHMS FOR SOLVING LARGE-SCALE NONLINEAR OPTIMIZATION PROBLEMS	279
	<i>Paul Kang-Hoh Phua, Daohua Ming, Weiguo Fan and Yan Zhang</i>	
1	Conventional Methods for Nonlinear Optimization	280
2	Parallel Quasi-Newton Algorithms	281
3	Vectorization and Fine-tuning Techniques	284
4	Computational Results	288
	References	293
16	SECOND ORDER STRICT CONVERSE DUALITY IN NONLINEAR FRACTIONAL PROGRAMMING	295
	<i>Xin Min Yang, Kok Lay Teo and Xiaoqi Yang</i>	
1	Introduction and Preliminaries	296
2	Second Order Strict Converse Duality I	298
3	Second Order Strict Converse Duality II	302
	References	305
	Part III OPTIMIZATION APPLICATIONS	
17	Chebyshev Optimization of Circular Arrays	309
	<i>Mattias Dahl, Ingvar Claesson, Sven Nordebo and Sven Nordholm</i>	
1	Introduction	310
2	Problem Formulation	311
3	The Complex Chebyshev Approximation Problem as a Semi-Infinite Linear Program	312
4	Semi-Infinite Linear Programming	313
5	Brief Outline of Linear Programming	315
6	Numerical Example	316
7	Summary	317
	References	317
18	Optimum Pole Position for Digital Laguerre Network with Least Square Error Criterion	321
	<i>H. H. Dam, Kok Lay Teo, Yanqun Liu and S. Nordebo</i>	
1	Introduction	322
2	Problem Formulation	322
3	Optimization Method	324
4	Simulation Studies	326
5	Conclusions	328
	References	329

19		
A MARKOV MODEL FOR THE STOCHASTIC OPTIMAL CONTROL OF A SOLAR POWERED CAR		331
<i>Phil Howlett</i>		
1 Introduction		332
2 Formulation		332
3 A Recursive Equation for the Optimal Controls		333
4 The Properties of the Optimal Controls		336
5 Some Elementary Examples		338
6 Conclusions		341
References		341
20		
THE PERSONNEL TASK SCHEDULING PROBLEM		343
<i>Mohan Krishnamoorthy and Andreas T Ernst</i>		
1 Introduction		344
2 The PTSP		344
3 Variants of the PTSP		348
4 Literature Review		357
5 Applications		359
6 Test Data		362
7 Conclusions		366
References		367
21		
ENVELOPE CONSTRAINED FILTER DESIGN: ROBUSTNESS ISSUES		369
<i>B. Vo and A. Cantoni</i>		
1 Introduction		370
2 Envelope Constrained Filtering		372
3 Robustness Issues		380
4 Conclusions		395
References		395
22		
A ROBUST NUMERICAL ALGORITHM FOR THE OPTIMAL CONTROL OF HEAT TRANSFER IN THE CONTINUOUS CASTING OF STEEL		399
<i>Y.H. Wu, M. Chuedoung and G. Zhang</i>		
1 Introduction		400
2 Heat Transfer Model		401
3 Statement of the Optimal Control Problem		403
4 Numerical Method for the Optimal Control Problem		404
5 Numerical Approximation of the Jacobian Matrix		406
6 Numerical Algorithm		407
7 An Illustrative Example		408
8 Conclusions		410
References		411

Preface

This edited book is dedicated to Professor N.U. Ahmed, a leading scholar and a renowned researcher in optimal control and optimization on the occasion of his retirement from the Department of Electrical Engineering at University of Ottawa in 1999.

The contributions of this volume are in the areas of optimal control, nonlinear optimization and optimization applications. They are mainly the improved and expanded versions of the papers selected from those presented in two special sessions of two international conferences. The first special session is Optimization Methods, which was organized by K.L. Teo and X.Q. Yang for the International Conference on Optimization and Variational Inequality, the City University of Hong Kong, Hong Kong, 1998. The other one is Optimal Control, which was organized by K.L. Teo and L. Caccetta for the Dynamic Control Congress, Ottawa, 1999.

This volume is divided into three parts: Optimal Control; Optimization Methods; and Applications. The Optimal Control part is concerned with computational methods, modeling and nonlinear systems. Three computational methods for solving optimal control problems are presented: (i) a regularization method for computing ill-conditioned optimal control problems, (ii) penalty function methods that appropriately handle final state equality constraints, and (iii) a multilevel optimization approach for the numerical solution of optimal control problems. In the fourth paper, the worst-case optimal regulation involving linear time varying systems is formulated as a minimax optimal control problem. The next three papers concern with nonlinear systems and their applications, such as the modified direct gradient descent control of nonlinear systems, the stability of impulsive delay differential equations, and the effect of acceleration on the performance and observability of the true proportional based guidance system.

In the Optimization Methods part, computational methods and algorithms are presented. These include a homogenized cutting plane method for solving the convex feasibility problem, exact algorithms for some hard knapsack problems, asymptotic rates analysis of SQP-type methods of feasible directions for nonlinear programming problems, nonlinear Lagrangian methods in constrained optimization problems, and parallel algorithms for solving large scale nonlinear programming problems.

In the Applications part, a number of practical real world problems are solved using optimization and optimal control techniques. They are: (i) the lobe design of a narrow-band antenna array in signal processing is formulated as a complex Chebyshev optimization problem and is solved by the semi-infinite linear programming technique; (ii) a global optimization method for the optimum pole selection of a digital Laguerre network; (iii) the Bellman principle of dynamic programming is applied to obtain an optimal control policy that maximizes the total distance to be traveled by a solar-powered car; (iv) the personnel task scheduling problem is explored in which a set of tasks with fixed start and end time is assigned to a heterogeneous workforce; and (v) a two-

phase heat transfer problem arising from the continuous steel casting process is solved as an optimal control problem.

We would like to express our warmest thanks to a number of referees for their careful and critical evaluation of the manuscripts. They include X. Huang (Chongqing Normal University), J. Lee (The Hong Kong Polytechnic University), D.H. Li (Hunan University), S.J. Li (Chongqing Jianzhu University), A. Lim (The Chinese University of Hong Kong), K.W. Lim (National University of Singapore), Y. Liu (The Hong Kong Polytechnic University), S. Nordholm (University of Karlskrona/Ronneby), B. Vo (Australian Telecommunication Research Institute), S. Wang (The University of Western Australia), W.Y. Yan (Curtin University of Technology), and Y.B. Zhao (Chinese Academy of Sciences).

Xiaoqi Yang, Kok Lay Teo and Lou Caccetta

An Appreciation of Professor N.U. Ahmed

Nasir U. AHMED was born in Bangladesh in 1934. He received his BSc degree in electrical engineering from Dhaka University, Bangladesh in 1956, MSc degree with Magna Cum Laude in electrical engineering from the University of Ottawa, Canada in 1963 and a PhD degree with Summa Cum Laude in electrical engineering also from the University of Ottawa in 1965. He was a Senior Scientific Office in the Pakistan Atomic Energy Commission before he returned to Canada as a Postdoctoral Fellow with the University of Alberta in 1967. He joined the University of Ottawa as an assistant professor in 1968, and was promoted to an associate professor in 1971. Prior to his retirement, he was a professor with the Department of Electrical Engineering of the University of Ottawa since 1976. Professor Ahmed served as the Chairman of Department of Electrical Engineering of the University of Ottawa from 1989 to 1992. He is now a Professor Emeritus of Systems Science in the School of Information Technology and Engineering, and the Department of Mathematics, University of Ottawa.

In view of his outstanding scientific achievements, Professor Ahmed has had many visiting positions at various institutes. He spent a year (1977) at the University of California at Berkeley as a Visiting Professor in the Department of Electrical and Computer Science. He spent the summer months of 1980-81 visiting the Department of Systems Science at the University of California at LA. He spent the winter of 1980-81 as a Visiting Professor at the University of New South Wales, and gave a series of lectures on partial differential equations and control of systems governed by PDE. In the summer of 1988, he was a Visiting Professor at the University of Western Australia. He presented a series of lectures on semigroup theory and its applications to physical and engineering sciences which was subsequently written as a monograph, entitled "Semigroup Theory with Applications to Systems and Control". This monograph was published by Longman Scientific and Technical in 1988. His other invited visitations include Banach Center in Warsaw, Poland; a number of prestigious universities in China ; and many well-known universities in USA and Canada. Professor Ahmed is also active in various professional societies, such as APEO, IEEE, AMS, and SIAM.

Professor Ahmed has been awarded numerous research grants from NSERC and DND Contract. He has graduated 17 PhD students, including K.L. Teo the second editor of this volume, and S. K. Biswas the co-author of the paper, "Worst-case Optimal Regulation of Linear Systems in the Presence of Structured Perturbation". Amongst the authors of the Volume, it is pleasing to note that K.H. Wong, V. Rehbock, H.H. Dam and B. Vo were students of Teo, and G. Peter is currently pursuing his PhD study under the supervision of K.H. Wong. Professor Ahmed has also graduated many masters students, and supervised numerous research associates and post doctoral fellows.

Professor Ahmed has written 5 excellent books, 18 invited papers, over 190 refereed international journal papers, 8 invited articles in edited books and encyclopedia, over 70 conference publications. He was keynote speakers for many important international conferences. He has served as members of editorial board of numerous international journals, including Journal of Dynamics and

Control; Dynamic Systems and Applications; International Journal of Science and Technology; Discussions Mathematicae; Differential inclusions; Mathematical Problems in Engineering: Theory and Applications; Discrete and Continuous Dynamic Systems; Dynamics of Continuous, Discrete and Impulsive Systems; and Communications in Applied Mathematics.

Professor Ahmed has also served as members of Organizing Committee of many International Conferences. His current research areas includes: (i) measure solutions for semilinear evolution equations on Banach spaces and their optimal control; (ii) mathematical modeling (PDE) of the dynamics of suspension bridges and their stability analysis and optimum design; (iii) mathematical modeling of the hemodynamics (hemolysis = red blood cell damage) of artificial heart based on Navier-Stokes equation in 3D and membrane equation in 2D and their optimal control subject to geometric and clinical constraints; and (iv) state space modeling of the dynamics of computer-communication network and their performance analysis.

Professor Ahmed has made many important fundamental contributions in applied functional analysis, stochastic processes, systems and control theory, and practical real world applications of control and optimization. A sample of these contributions are listed as follows:

(1) Developed Fourier analysis on Wiener measure space and introduced the concepts of a vector space for nonlinear functionals of Brownian motion.

(2) Discovered a class of Generalized Functionals of Brownian Motion and constructed a locally convex topological vector space. (This generalizes Hidas generalized functionals of Brownian Motion and opens up the prospect of much wider applications). It has applications in: (i) heat equations with nonlinear (Steffan-Boltzman) boundary conditions; and (ii) modeling turbulence in fluid mechanics. Recently this work was further extended to the space of generalized functionals of Gaussian random fields and evolution equations thereon. These generalized results have applications in the construction of solutions of stochastic Navier-Stokes equations, etc.

(3) Developed existence theorems for optimal controls and necessary conditions of optimality for systems governed by functional-differential equations in finite dimensional spaces.

(4) Developed existence theorems for partially observed diffusions and stochastic functional differential equations in finite dimensional spaces.

(5) Developed optimal control theory for stochastic evolution equations on Banach space with random operator valued coefficients.

(6) Pioneered the development of optimal control theory for general nonlinear evolution equations and differential inclusions on Banach spaces. (This resulted in the book, entitled "Optimal Control of Distributed Parameter Systems", North Holland, 1981, Co-author K.L.Teo)

(7) Introduced a general class of stochastic evolution equations and differential inclusions on Banach space driven by generalized Brownian motion. Application to stochastic partial differential equations with both distributed and boundary noise was demonstrated.

(8) Developed a selection theorem for multivalued maps in reflexive Banach spaces which has been applied by control theorists in infinite dimensional systems.

(9) Developed a general theory for optimization and identification of unbounded operators in evolution equations on Banach Space, which led to the publication of the Monogram "Elements of Finite Dimensional System and Control Theory" (Pitman Research Notes in Mathematics Series, Vol. 184, 1988). (This work provides for the first time a unified approach to inverse problems or identification problems.)

(10) Introduced the concept of differential inclusions for stochastic systems, and subsequently, its applications in control theory. This has been applied to stochastic systems with uncertain parameters or systems with incomplete dynamic models.

(11) Developed nonlinear filter theory for abstract Evolution equations on Hilbert space, which have widespread applications in systems governed by PDE and distributed signal processing. This work was done in collaboration with Professors J.Zabczyk, Polish Academy of Sciences, and Professor M. Fuhrman, Polytechnic University of Milan.

(12) Developed a general theory of partially observed control for nonlinear stochastic differential equations on Hilbert Space. This was an open problems for a decade.

(13) Developed theory of generalized solutions for systems governed by m -times integrated semigroups, which covers the class of distribution semigroups of J.L. Lions. This has much broader applications, including PDE containing non densely defined unbounded operators.

(14) Developed an interesting theory of measure solutions for semilinear evolution equations on Banach spaces both for Deterministic and Stochastic Systems.

(15) Developed a complete stochastic partial differential equation model for suspension bridge, and provided stability analysis.

(16) Introduced the concept of Orlicz stability for general nonlinear systems, covering nonlinearities with exponential growth .

(17) Constructed a complete stochastic dynamic model for large power systems network and computer communication networks, and developed relevant optimization techniques.

(18) Developed a stochastic jump process model for filtering the integrated navigation signals for DND.

(19) Constructed a complete dynamic model for flexible spacecraft based on Hamilton's principle, provided answers to various questions on stability and stabilizability, and developed techniques for constructing stabilizing controls.

(20) Constructed a complete mathematical dynamic model for space stations, and obtained important results on its stabilizing feedback controls. This was presented at JPL-NASA Conference, California , (1989).

(21) Based on Navier-Stokes equation, a complete mathematical model of the hemo-dynamics of artificial heart was constructed. The model was used

to compute optimal controls, which minimize hemolysis (damage to red blood cells).

(22) Developed a rigorous mathematical model for suspension bridge with full analysis and complete illustration by numerical and simulation results.

(23) His latest book is on filtering, entitled "Linear and Nonlinear Filtering for Scientists and Engineers" published by World Scientific Publishers, (1999). This book presents many interesting new results along with general and powerfully numerical techniques for solving nonlinear filtering problems.

The editors of this Volume have had the privilege of knowing Professor Ahmed, personally and professionally. In particular, the second editor has known him for nearly 30 years, first as his thesis supervisor and mentor, and subsequently as his close colleague and friend. Professor Ahmed's work has influenced the scientific activity of many researchers in the area of control and optimization and their applications. More importantly, Professor Ahmed has won the admiration and affection of those who know and benefited from him. Professor Ahmed is not only an outstanding scholar, but more importantly, he is an excellent colleague and friend.

A Publication List of Professor N.U. Ahmed

Professor Ahmed has written 5 books, 8 invited articles in books and encyclopedia, 193 refereed journal publication, 70 refereed conference publications, 18 invited papers, 2 conference presentations without proceedings and 4 contract reports. The total is 300.

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