

AIMS Series on Applied Mathematics

Volume 2

Introduction to the Mathematical Theory of Control

Alberto Bressan and Benedetto Piccoli

With 102 figures and 107 exercises



American Institute of Mathematical Sciences

Contents

1	Introduction	1
2	Review of Differential Equations	13
	2.1 Fundamental theory	14
	2.2 Linear systems	21
	2.3 Differentiability with respect to initial data	26
	2.4 A transversality theorem	30
	Problems	32
3	Control Systems	35
	3.1 An equivalent differential inclusion	36
	3.2 Fundamental properties of trajectories	37
	3.3 Closure	44
	3.4 Density	47
	3.5 Reachable sets	51
	3.6 Linear systems	56
	3.7 Local controllability of nonlinear systems	59
	3.8 Lie brackets and controllability	61
	3.9 Chattering controls	65
	3.10 The Bang-Bang theorem	67
	Problems	69
4	Asymptotic stabilization	75
	4.1 Lyapunov stability	75
	4.2 Stabilization of linear control systems	79
	4.3 Stabilization of nonlinear systems	83
	Problems	85
5	Existence of Optimal Controls	87
	5.1 Mayer problems	87
	5.2 The problem of Bolza	93

Problems	95
6 Necessary conditions	99
6.1 The Mayer problem with free terminal point	100
6.2 Computation of optimal controls	104
6.3 The Mayer problem with terminal constraints	110
6.4 Variable terminal time	115
6.5 The problem of Bolza	119
6.6 Linear-quadratic optimal control	125
Problems	127
7 Sufficient Conditions	133
7.1 Existence + PMP.	134
7.2 Convexity + PMP.	135
7.3 Dynamic Programming	137
7.4 Relations between the P.M.P. and the P.D.E. of Dynamic Programming	148
7.5 Linear-quadratic case	150
7.6 Optimal syntheses	154
Problems	161
8 Viscosity solutions for Hamilton-Jacobi equations	165
8.1 The method of characteristics	166
8.2 One-sided differentials	170
8.3 Viscosity solutions	174
8.4 Stability properties	176
8.5 Comparison theorems	178
8.6 Dynamic programming (revisited)	185
8.7 The Hamilton-Jacobi-Bellman equation	189
8.8 Infinite horizon problems	192
Problems	197
9 Patchy Feedbacks	199
9.1 Patchy vector fields	201
9.2 Asymptotic feedback stabilization	206
9.3 Robustness	211
9.4 Nearly optimal patchy feedbacks	219
Problems	229
10 Impulsive Control Systems	233
10.1 Mechanical systems controlled by moving constraints	235
10.2 Generalized trajectories for commuting vector fields	241
10.3 The non-commutative case: graph completions	247
10.4 Systems with quadratic impulses	252
10.5 Optimization problems for commutative impulsive systems	257

Problems	259
A Appendices	263
A.1 Normed spaces	263
A.2 Banach's contraction mapping theorem	265
A.3 Brouwer's fixed point theorem	267
A.4 A compactness theorem	273
A.5 Review of Lebesgue measure theory	274
A.6 Differentiability of Lipschitz continuous functions	277
A.7 Multifunctions	279
A.8 Convex sets	283
A.9 Convex cones	288
A.10 Lie brackets and Frobenius' theorem	294
Problems	300
References	305
Index	311