MA-H-613

2860-8167

Gilles Aubert Pierre Kornprobst

## Mathematical Problems in Image Processing

Partial Differential Equations and the Calculus of Variations

Second Edition





## Contents

	Foreword	vn				
	Preface to the Second Edition	хi				
	Preface to the First Edition	XV				
	Guide to the Main Mathematical Concepts and					
	Their Application x	XXV				
	Notation and Symbols xx	vii				
1 Introduction						
	<ul> <li>1.1 The Image Society.</li> <li>1.2 What Is a Digital Image?</li> <li>1.3 About Partial Differential Equations (PDEs).</li> <li>1.4 Detailed Plan.</li> </ul>	3 5				
2	Mathematical Preliminaries	29				
	How to Read This Chapter  2.1 The Direct Method in the Calculus of Variations.  2.1.1 Topologies on Banach Spaces.  2.1.2 Convexity and Lower Semicontinuity.  2.1.3 Relaxation.  2.1.4 About T-Convergence.	30 30 32 37 40				
	2.2 The Space of Functions of Bounded Variation	42				

		2.2.1	Basic Definitions on Measures	43
		2.2.2	Definition of $BV(\ddot{U})$ :	45
		2.2.3	Properties of $BV(\ddot{U})$	46
		2.2.4	Convex Functions of Measures	
	2.3	Viscos	sity Solutions in PDEs	. 50
		2.3.1	About the Eikonal Equation	50
		2.3.2	Definition of Viscosity Solutions	. 52
		2.3.3	About the Existence	. 54
		2.3.4	About the Uniqueness	55
	2.4	Eleme	ents of Differential Geometry: Curvature	
		2.4.1	Parametrized Curves	
		2.4.2	Curves as Isolevel of a Function u.	. 58
		2.4.3	Images as Surfaces	
	2.5	Other	Classical Results Used in This Book	60
		2.5.1	Inequalities	
		2.5.2	Calculus Facts	
		2.5.3	About Convolution and Smoothing	
		2.5.4	Uniform Convergence	
		2.5.5	Dominated Convergence Theorem	
		2.5.6	Well-Posed Problems	64
n	Ima	zo Dog	touction	65
3			toration d This Chapter	
	3.1			
	3.1		e Degradation Energy Method	
	3.2	3.2.1	An Inverse Problem.	
		3.2.1	Regularization of the Problem	
		3.2.3	Existence and Uniqueness of a Solution for	09
		3.2.3	the Minimization Problem	72
		3.2.4	Toward the Numerical Approximation.	
		3.2.4	The Projection Approach	
			The Half-Quadratic Minimization Approach	
		3.2.5	Some Invariances and the Role of A	
		3.2.6	Some Remarks on the Nonconvex Case.	
	3.3		Based Methods.	
	3.3	3.3.1	Smoothing PDEs.	
		5.5.1	The Heat Equation	
			Nonlinear Diffusion.	
			The Alvarez-Guichard-Lions-Morel	
			Scale Space Theory.	.107
			Weickert's Approach	
			Surface Based Approaches	
		3.3.2	Smoothing-Enhancing PDEs.	
			The Perona and Malik Model	121

Contents	
	XX1

			Regularization of the Perona and Malik Model:	
			Catté et al	.123
		3.3.3	Enhancing PDEs	
			The Osher and Rudin Shock Filters	
			A Case Study: Construction of a Solution by	
			the Method of Characteristics	.130
			Comments on the Shock-Filter Equation	.134
		3.3.4	Neighborhood Filters, Nonlocal Means Algorithm,	
			and PDEs	.137
			Neighborhood Filters	.138
			How to Suppress the Staircase Effect?	
			Nonlocal Means Filter (NL-Means).	.146
4	The	Segme	entation Problem	149
	How	to Read	d This Chapter.	.149
	4.1	Defini	ition and Objectives	150
	4.2	The N	Mumford and Shah Functional	.153
		4.2.1	A Minimization Problem	.153
		4.2.2	The Mathematical Framework for the	
			Existence of a Solution	.154
		4.2.3	Regularity of the Edge Set.	
		4.2.4	Approximations of the Mumford and Shah	
			Functional	166
		4.2.5	Experimental Results . '	
	4.3	Geode	esic Active Contours and the Level-Set Method	173
		4.3.1	The Kass-Witkin-Terzopoulos model	.173
		4.3.2	The Geodesic Active Contours Model	.175
		4.3.3	The Level-Set Method	.182
		4.3.4	The Reinitialization Equation	.194
			Characterization of the Distance Function	195
			Existence and Uniqueness	.198
		4.3.5	Experimental Results	206
		4.3.6	About Some Recent Advances	208
			Global Stopping Criterion	
			Toward More General Shape Representation	211
5	Othe	er Cha	llenging Applications	213
			d This Chapter	.213
	5.1		enting Some Image Parts by Inpainting	215
	<del>.</del>	5.1.1	Introduction.	215
		5.1.2	Variational Models	216
			The Masnou and Morel Approach	216
			The Ballester et al. Approach	218
			The Chan and Shen Total Variation Minimization	0
			Approach	220

	5.1.3	PDE-Based Approaches	222
		The Bertalmio et al. Approach	.223
		The Chan and Shen Curvature-Driven Diffusion	
		Approach	.224
	5.1.4	Discussion	
5.2	Decon	nposing an Image into Geometry and Texture	228
	5.2.1	Introduction	
	5.2.2	A Space for Modeling Oscillating Patterns	
	5.2.3	Meyer's Model	232
	5.2.4	An Algorithm to Solve Meyer's Model	
		Prior Numerical Contribution	
		The Aujol et al. Approach	.234
		Study of the Asymptotic Case	
		Back to Meyer's Model	.242
	5.2.5	Experimental Results	245
		Denoising Capabilities	.245
		Dealing With Texture	248
	5.2.6	About Some Recent Advances	248
5.3	Seque	nce Analysis	249
	5.3.1	Introduction	.249
	5.3.2	The Optical Flow: An Apparent Motion	.250
		The Optical Flow Constraint (OFC)	.252
		Solving the Aperture Problem	253
		Overview of a Discontinuity-Preserving	
		Variational Approach	256
		Alternatives to the OFC	
	5.3.3	Sequence Segmentation.	
		Introduction	
		A Variational Formulation	264
		Mathematical Study of the	
		Time-Sampled Energy	
		Experiments	
	5.3.4	Sequence Restoration	
		Principles of Video Inpainting	
		Total Variation (TV) Minimization Approach	
		Motion Compensated (MC) Inpainting	
5.4	Image	e Classification.	
		Introduction.	. 281
	5.4.2	A Level-Set Approach for	
		Image Classification	282
	5.4.3	A Variational Model for Image Classification and	
_		Restoration	. 290
5.5		r-Valued Images	
	5.5.1	Introduction.	
	5.5.2	An Extended Notion of Gradient	.300

			Contents		xxiii
		5.5.3	The Energy Method.		.300
		5.5.4	PDE-Based Methods		.302
A	Intr	oductio	on to Finite Difference Methods		307
	How	to Read	This Chapter		307
	A.1	Defini	tions and Theoretical Considerations Illustrated		
		by the	1-D Parabolic Heat Equation		308
		A.1.1	=		
		A.1.2	Convergence.		311
		A.1.3			313
		A.1.4			313
		A.1.5	•		
	A.2	Hyper	bolic Equations		
	A.3		ence Schemes in Image Analysis		
		A.3.1	Getting Started		329
		A.3.2	Image Restoration by Energy Minimization		333
		A.3.3	Image Enhancement by the Osher and Rudin		
			Shock Filters '		.336
		A.3.4	Curve Evolution with the Level-Set Method		338
			Mean Curvature Motion		.339
			Constant Speed Evolution	٠	.340
			The Pure Advection Equation	٠	.341
			Image Segmentation by the Geodesic		
			Active Contour Model	•	.342
В	Exp	erimen	t Yourself!		343
			l This Chapter		.343
	B.1	The C	Img Library		.344
	B.2		Is Available Online?		.344
Re	eferen	ices			349
[n	dex				373