

The Essential Guide to
**Image
Processing**

AL BOVIK

FREE
SOFTWARE

INCLUDED



The Essential Guide to Image Processing

Second Edition

EDITOR

AI Bovik

*Department of Electrical and Computer Engineering
The University of Texas at Austin
Austin, Texas*



ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Academic Press is an imprint of Elsevier



Academic Press is an imprint of Elsevier
30 Corporate Drive, Suite 400, Burlington, MA 01803, USA
525 B Street, Suite 1900, San Diego, California 92101-4495, USA
84 Theobald's Road, London WC1X 8RR, UK

Copyright © 2009, Elsevier Inc. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Permissions may be sought directly from Elsevier's Science & Technology Rights Department in Oxford, UK: phone: (+44) 1865 843830, fax: (+44) 1865 853333, E-mail: permissions@elsevier.com. You may also complete your request online via the Elsevier homepage (<http://elsevier.com>), by selecting "Support & Contact" then "Copyright and Permission" and then "Obtaining Permissions."

Library of Congress Cataloging-in-Publication Data

Application submitted

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library.

ISBN: 978-0-12-374457-9

For information on all Academic Press publications
visit our Web site at www.elsevierdirect.com

Typeset by: diacriTech, India

Printed in the United States of America
09 10 11 12 9 8 7 6 5 4 3 2 1

Working together to grow
libraries in developing countries

www.elsevier.com | www.bookaid.org | www.sabre.org

ELSEVIER

BOOK AID
International

Sabre Foundation

The Essential Guide to Image Processing

Second Edition

Preface

The visual experience is the principal way that humans sense and communicate with their world. We are visual beings and images are being made increasingly available to us in electronic digital format via digital cameras, the internet, and hand-held devices with large-format screens. With much of the technology being introduced to the consumer marketplace being rather new, digital image processing remains a “hot” topic and promises to be one for a very long time. Of course, digital image processing has been around for quite awhile, and indeed, methods pervade nearly every branch of science and engineering. One only has to view the latest space telescope images or read about the newest medical image modality to be aware of this.

With this introduction, welcome to *The Essential Guide to Image Processing*! The reader will find that this *Guide* covers introductory, intermediate and advanced topics of digital image processing, and is intended to be highly accessible for those entering the field or wishing to learn about the topic for the first time. As such, the *Guide* can be effectively used as a classroom textbook. Since many intermediate and advanced topics are also covered, the *Guide* is a useful reference for the practicing image processing engineer, scientist, or researcher. As a learning tool, the *Guide* offers easy-to-read material at different levels of presentation, including introductory and tutorial chapters on the most basic image processing techniques. Further, there is included a chapter that explains digital image processing software that is included on a CD with the book. This software is part of the award-winning *SIVA* educational courseware that has been under development at The University of Texas for more than a decade, and which has been adopted for use by more than 400 educational, industry, and research institutions around the world. Image processing educators are invited these user-friendly and intuitive live image processing demonstrations into their teaching curriculum.

The *Guide* contains 27 chapters, beginning with an introduction and a description of the educational software that is included with the book. This is followed by tutorial chapters on the basic methods of gray-level and binary image processing, and on the essential tools of image Fourier analysis and linear convolution systems. The next series of chapters describes tools and concepts necessary to more advanced image processing algorithms, including wavelets, color, and statistical and noise models of images. Methods for improving the appearance of images follow, including enhancement, denoising and restoration (deblurring). The important topic of image compression follows, including chapters on lossless compression, the JPEG and JPEG-2000 standards, and wavelet image compression. Image analysis chapters follow, including two chapters on edge detection and one on the important topic of image quality assessment. Finally, the *Guide* concludes with six exciting chapters dealing explaining image processing applications on such diverse topics as image watermarking, fingerprint recognition, digital microscopy, face recognition, and digital tomography. These have been selected for their timely interest, as well as their illustrative power of how image processing and analysis can be effectively applied to problems of significant practical interest.

The *Guide* then concludes with a chapter pointing towards the topic of digital *video* processing, which deals with visual signals that vary over time. These very broad and more advanced field is covered in a companion volume suitably entitled *The Essential Guide to Video Processing*. The topics covered in the two companion *Guides* are, of course closely related, and it may interest the reader that earlier editions of most of this material appeared in a highly popular but gigantic volume known as *The Handbook of Image and Video Processing*. While this previous book was very well-received, its sheer size made it highly un-portable (but a fantastic doorstep). For this newer rendition, in addition to updating the content, I made the decision to divide the material into two distinct books, separating the material into coverage of still images and moving images (video). I am sure that you will find the resulting volumes to be information-rich as well as highly accessible.

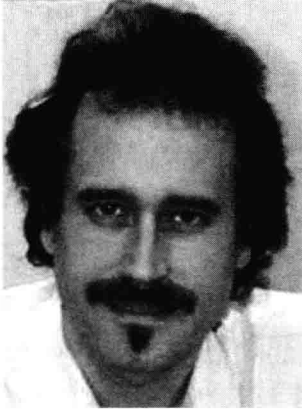
As Editor and Co-Author of *The Essential Guide to Image Processing*, I would thank the many co-authors who have contributed such wonderful work to this *Guide*. They are all models of professionalism, responsiveness, and patience with respect to my cheerleading and cajoling. The group effort that created this book is much larger, deeper, and of higher quality than I think that any individual could have created. Each and every chapter in this *Guide* has been written by a carefully selected distinguished specialist, ensuring that the greatest depth of understanding be communicated to the reader. I have also taken the time to read each and every word of every chapter, and have provided extensive feedback to the chapter authors in seeking to perfect the book. Owing primarily to their efforts, I feel certain that this *Guide* will prove to be an essential and indispensable resource for years to come.

I would also like to thank the staff at Elsevier—the Senior Commissioning Editor, Tim Pitts, for his continuous stream of ideas and encouragement, and for keeping after me to do this project; Melanie Benson for her tireless efforts and incredible organization and accuracy in making the book happen; Eric DeCicco, the graphic artist for his efforts on the wonderful cover design, and Greg Dezarn-O'Hare for his flawless typesetting.

National Instruments, Inc., has been a tremendous support over the years in helping me develop courseware for image processing classes at The University of Texas at Austin, and has been especially generous with their engineer's time. I particularly thank NI engineers George Panayi, Frank Baumgartner, Nate Holmes, Carleton Heard, Matthew Slaughter, and Nathan McKimpson for helping to develop and perfect the many Labview demos that have been used for many years and are now available on the CD-ROM attached to this book.

Al Bovik
Austin, Texas
April, 2009

About the Author



Al Bovik currently holds the Curry/Cullen Trust Endowed Chair Professorship in the Department of Electrical and Computer Engineering at The University of Texas at Austin, where he is the Director of the Laboratory for Image and Video Engineering (LIVE). He has published over 500 technical articles and six books in the general area of image and video processing and holds two US patents.

Dr. Bovik has received a number of major awards from the IEEE Signal Processing Society, including the Education Award (2007); the Technical Achievement Award (2005), the Distinguished Lecturer Award (2000); and the Meritorious Service Award (1998). He is also a recipient of the IEEE Third Millennium Medal (2000), and has won two journal paper awards from the Pattern Recognition Society (1988 and 1993). He is a Fellow of the IEEE, a Fellow of the Optical Society of America, and a Fellow of the Society of Photo-Optical and Instrumentation Engineers. Dr. Bovik has served Editor-in-Chief of the *IEEE Transactions on Image Processing* (1996–2002) and created and served as the first General Chairman of the *IEEE International Conference on Image Processing*, which was held in Austin, Texas, in 1994.

Contents

Preface.....	xix
About the Author.....	xxi

CHAPTER 1	Introduction to Digital Image Processing	1
1.1	Types of Images	2
1.2	Scale of Images	4
1.3	Dimension of Images	6
1.4	Digitization of Images	6
1.5	Sampled Images	7
1.6	Quantized Images	9
1.7	Color Images	13
1.8	Size of Image Data	15
1.9	Objectives of this <i>Guide</i>	17
1.10	Organization of the <i>Guide</i>	19
	Reference	21
 CHAPTER 2	 The SIVA Image Processing Demos	 23
2.1	Introduction.....	23
2.2	LabVIEW for Image Processing.....	24
	2.2.1 The LabVIEW Development Environment.....	25
	2.2.2 Image Processing and Machine Vision in LabVIEW ...	27
2.3	Examples from the SIVA Image Processing Demos	31
2.4	Conclusions	38
	References	41
 CHAPTER 3	 Basic Gray Level Image Processing	 43
3.1	Introduction.....	43
3.2	Notation	44
3.3	Image Histogram	44
3.4	Linear Point Operations on Images	47
	3.4.1 Additive Image Offset	48
	3.4.2 Multiplicative Image Scaling	50
	3.4.3 Image Negative	51
	3.4.4 Full-Scale Histogram Stretch	53
3.5	Nonlinear Point Operations on Images	55
	3.5.1 Logarithmic Point Operations.....	55
	3.5.2 Histogram Equalization	56
	3.5.3 Histogram Shaping	59

3.6	Arithmetic Operations Between Images.....	60
3.6.1	Image Averaging for Noise Reduction.....	61
3.6.2	Image Differencing for Change Detection	63
3.7	Geometric Image Operations	65
3.7.1	Nearest Neighbor Interpolation	65
3.7.2	Bilinear Interpolation	66
3.7.3	Image Translation	66
3.7.4	Image Rotation	67
3.7.5	Image Zoom	67
CHAPTER 4	Basic Binary Image Processing	69
4.1	Introduction.....	69
4.2	Image Thresholding	71
4.3	Region Labeling	77
4.3.1	Region Labeling Algorithm	77
4.3.2	Region Counting Algorithm	78
4.3.3	Minor Region Removal Algorithm	78
4.4	Binary Image Morphology	79
4.4.1	Logical Operations	79
4.4.2	Windows	80
4.4.3	Morphological Filters	82
4.4.4	Morphological Boundary Detection	90
4.5	Binary Image Representation and Compression.....	92
4.5.1	Run-Length Coding	93
4.5.2	Chain Coding	94
CHAPTER 5	Basic Tools for Image Fourier Analysis	97
5.1	Introduction.....	97
5.2	Discrete-Space Sinusoids	97
5.3	Discrete-Space Fourier Transform.....	100
5.3.1	Linearity of DSFT	101
5.3.2	Inversion of DSFT	101
5.3.3	Magnitude and Phase of DSFT	101
5.3.4	Symmetry of DSFT	102
5.3.5	Translation of DSFT	102
5.3.6	Convolution and the DSFT	103
5.4	2D Discrete Fourier Transform (DFT)	103
5.4.1	Linearity and Invertibility of DFT	105
5.4.2	Symmetry of DFT	106
5.4.3	Periodicity of DFT	106
5.4.4	Image Periodicity Implied by DFT	106
5.4.5	Cyclic Convolution Property of the DFT	107
5.4.6	Linear Convolution Using the DFT	110
5.4.7	Computation of the DFT	112
5.4.8	Displaying the DFT	112

5.5	Understanding Image Frequencies and the DFT	115
5.5.1	Frequency Granularity	115
5.5.2	Frequency Orientation	118
5.6	Related Topics in this <i>Guide</i>	121
CHAPTER 6	Multiscale Image Decompositions and Wavelets	123
6.1	Overview	123
6.2	Pyramid Representations	126
6.2.1	Decimation and Interpolation	126
6.2.2	Gaussian Pyramid	127
6.2.3	Laplacian Pyramid	128
6.3	Wavelet Representations	129
6.3.1	Filter Banks	129
6.3.2	Wavelet Decomposition	130
6.3.3	Discrete Wavelet Bases	133
6.3.4	Continuous Wavelet Bases	135
6.3.5	More on Wavelet Image Representations	136
6.3.6	Relation to Human Visual System	137
6.3.7	Applications	138
6.4	Other Multiscale Decompositions	138
6.4.1	Undecimated Wavelet Transform	138
6.4.2	Wavelet Packets	138
6.4.3	Geometric Wavelets	139
6.5	Conclusion	140
	References	140
CHAPTER 7	Image Noise Models	143
7.1	Summary	143
7.2	Preliminaries	143
7.2.1	What is Noise?	143
7.2.2	Notions of Probability	144
7.3	Elements of Estimation Theory	146
7.4	Types of Noise and Where They Might Occur	149
7.4.1	Gaussian Noise	149
7.4.2	Heavy Tailed Noise	150
7.4.3	Salt and Pepper Noise	154
7.4.4	Quantization and Uniform Noise	155
7.4.5	Photon Counting Noise	156
7.4.6	Photographic Grain Noise	159
7.5	CCD Imaging	160
7.6	Speckle	161
7.6.1	Speckle in Coherent Light Imaging	161
7.6.2	Atmospheric Speckle	165

7.7	Conclusions	166
	References	167
CHAPTER 8	Color and Multispectral Image Representation and Display	169
8.1	Introduction	169
8.2	Preliminary Notes on Display of Images	170
8.3	Notation and Prerequisite Knowledge	174
8.3.1	Practical Sampling	174
8.3.2	One-Dimensional Discrete System Representation	175
8.3.3	Multidimensional System Representation	177
8.4	Analog Images as Physical Functions	179
8.5	Colorimetry	180
8.5.1	Color Sampling	182
8.5.2	Discrete Representation of Color-Matching	183
8.5.3	Properties of Color-Matching Functions	184
8.5.4	Notes on Sampling for Color Aliasing	189
8.5.5	A Note on the Nonlinearity of the Eye	191
8.5.6	Uniform Color Spaces	191
8.6	Sampling of Color Signals and Sensors	193
8.7	Color I/O Device Calibration	196
8.7.1	Calibration Definitions and Terminology	196
8.7.2	CRT Calibration	197
8.7.3	Scanners and Cameras	198
8.7.4	Printers	199
8.7.5	Calibration Example	200
8.8	Summary and Future Outlook	202
	References	202
CHAPTER 9	Capturing Visual Image Properties with Probabilistic Models	205
9.1	The Gaussian Model	207
9.2	The Wavelet Marginal Model	211
9.3	Wavelet Local Contextual Models	215
9.4	Discussion	220
	References	220
CHAPTER 10	Basic Linear Filtering with Application to Image Enhancement	225
10.1	Introduction	225
10.2	Impulse Response, Linear Convolution, and Frequency Response	227
10.3	Linear Image Enhancement	230
10.3.1	Moving Average Filter	231

	10.3.2	Ideal Lowpass Filter	233
	10.3.3	Gaussian Filter	236
10.4		Discussion	239
		References	239
CHAPTER 11	Multiscale Denoising of Photographic Images		241
	11.1	Introduction	241
	11.2	Distinguishing Images from Noise in Multiscale Representations	242
	11.3	Subband Denoising—A Global Approach	244
	11.3.1	Band Thresholding	244
	11.3.2	Band Weighting	247
	11.4	Subband Coefficient Denoising—A Pointwise Approach	249
	11.4.1	Coefficient Thresholding	250
	11.4.2	Coefficient Weighting	252
	11.5	Subband Neighborhood Denoising—Striking a Balance	253
	11.5.1	Neighborhood Thresholding	253
	11.5.2	Neighborhood Weighting	256
	11.6	Statistical Modeling for Optimal Denoising	257
	11.6.1	The Bayesian View	258
	11.6.2	Empirical Bayesian Methods	258
	11.7	Conclusions	259
		References	260
CHAPTER 12	Nonlinear Filtering for Image Analysis and Enhancement		263
	12.1	Introduction	263
	12.2	Weighted Median Smoothers and Filters	264
	12.2.1	Running Median Smoothers	264
	12.2.2	Weighted Median Smoothers	267
	12.2.3	Weighted Median Filters	275
	12.3	Image Noise Cleaning	277
	12.4	Image Zooming	282
	12.5	Image Sharpening	284
	12.6	Conclusion	289
		References	290
CHAPTER 13	Morphological Filtering		293
	13.1	Introduction	293
	13.2	Morphological Image Operators	294
	13.2.1	Morphological Filters for Binary Images	294
	13.2.2	Morphological Filters for Gray-level Images	295
	13.2.3	Universality of Morphological Operators	296
	13.2.4	Median, Rank, and Stack Filters	297

	13.2.5 Algebraic Generalizations of Morphological Operators.....	298
13.3	Morphological Filters for Image Enhancement.....	299
	13.3.1 Noise Suppresion and Image Smoothing	300
	13.3.2 Connected Filters for Smoothing and Simplification	301
	13.3.3 Contrast Enhancement.....	305
13.4	Morphological Operators for Template Matching.....	307
	13.4.1 Morphological Correlation	307
	13.4.2 Binary Object Detection and Rank Filtering	308
	13.4.3 Hit-Miss Filter	309
13.5	Morphological Operators for Feature Detection	309
	13.5.1 Edge Detection.....	309
	13.5.2 Peak / Valley Blob Detection	314
13.6	Design Approaches for Morphological Filters	317
13.7	Conclusions	319
	References	319
CHAPTER 14	Basic Methods for Image Restoration and Identification	323
14.1	Introduction.....	323
14.2	Blur Models	326
	14.2.1 No Blur	327
	14.2.2 Linear Motion Blur	327
	14.2.3 Uniform Out-of-Focus Blur	329
	14.2.4 Atmospheric Turbulence Blur	330
14.3	Image Restoration Algorithms	330
	14.3.1 Inverse Filter	332
	14.3.2 Least-Squares Filters.....	332
	14.3.3 Iterative Filters	338
	14.3.4 Boundary Value Problem	342
14.4	Blur Identification Algorithms	343
	14.4.1 Spectral Blur Estimation	344
	14.4.2 Maximum Likelihood Blur Estimation	345
	References	347
CHAPTER 15	Iterative Image Restoration	349
15.1	Introduction.....	349
15.2	Iterative Recovery Algorithms.....	350
15.3	Spatially Invariant Degradation.....	351
	15.3.1 Degradation Model.....	351
	15.3.2 Basic Iterative Restoration Algorithm	351
	15.3.3 Convergence	352

	15.3.4	Reblurring.....	354
	15.3.5	Experimental Results	355
15.4		Matrix-Vector Formulation	361
	15.4.1	Basic Iteration.....	362
	15.4.2	Least-Squares Iteration.....	362
	15.4.3	Constrained Least-Squares Iteration	363
	15.4.4	Spatially Adaptive Iteration	367
15.5		Use of Constraints	368
	15.5.1	Experimental Results	370
15.6		Additional Considerations	371
	15.6.1	Other Forms of the Iterative Algorithm.....	371
	15.6.2	Hierarchical Bayesian Image Restoration	372
	15.6.3	Blind Deconvolution	374
	15.6.4	Additional Applications	375
15.7		Discussion	381
		References	381
CHAPTER 16		Lossless Image Compression	385
16.1		Introduction.....	385
16.2		Basics of Lossless Image Coding	386
16.3		Lossless Symbol Coding	390
	16.3.1	Basic Concepts from Information Theory	391
	16.3.2	Context-Based Entropy Coding	394
	16.3.3	Huffman Coding	395
	16.3.4	Arithmetic Coding.....	399
	16.3.5	Lempel-Ziv Coding.....	404
	16.3.6	Elias and Exponential-Golomb Codes	406
16.4		Lossless Coding Standards	410
	16.4.1	The JBIG and JBIG2 Standards	410
	16.4.2	The Lossless JPEG Standard	411
	16.4.3	The JPEG2000 Standard	412
16.5		Other Developments in Lossless Coding	413
	16.5.1	CALIC	413
	16.5.2	Perceptually Lossless Image Coding.....	415
		References	417
CHAPTER 17		JPEG and JPEG2000	421
17.1		Introduction.....	421
17.2		Lossy JPEG Codec Structure	423
	17.2.1	Encoder Structure	423
	17.2.2	Decoder Structure	425
17.3		Discrete Cosine Transform	425
17.4		Quantization	426
	17.4.1	DCT Coefficient Quantization Procedure	426
	17.4.2	Quantization Table Design.....	429

17.5	Coefficient-to-Symbol Mapping and Coding	432
17.5.1	DC Coefficient Symbols	432
17.5.2	Mapping AC Coefficient to Symbols	433
17.5.3	Entropy Coding	434
17.6	Image Data Format and Components	435
17.7	Alternative Modes of Operation	436
17.7.1	Progressive Mode	437
17.7.2	Hierarchical Mode	439
17.8	JPEG Part 3	441
17.8.1	Variable Quantization	441
17.8.2	Tiling	443
17.9	The JPEG2000 Standard	445
17.10	The JPEG2000 Part 1: Coding Architecture	446
17.10.1	Preprocessing: Tiling, Level Offset, and Color Transforms	447
17.10.2	Discrete Wavelet Transform (DWT)	448
17.10.3	Quantization and Inverse Quantization	449
17.10.4	Precincts and Code-blocks	450
17.10.5	Entropy Coding	450
17.10.6	Bitstream Organization	454
17.10.7	Additional Features	455
17.11	Performance and Extensions	457
17.11.1	Comparison of Performance	457
17.11.2	Part 2 Extensions	457
17.12	Additional Information	458
17.12.1	Useful Information and Links for the JPEG Standard	458
17.12.2	Useful Information and Links for the JPEG2000 Standard	458
	References	459
CHAPTER 18	Wavelet Image Compression	463
18.1	What Are Wavelets: Why Are They Good for Image Coding?	463
18.2	The Compression Problem	469
18.3	The Transform Coding Paradigm	471
18.3.1	Transform Structure	474
18.3.2	Quantization	474
18.3.3	Entropy Coding	475
18.4	Subband Coding: The Early Days	476
18.5	New and More Efficient Class of Wavelet Coders	478
18.5.1	Zerotree-Based Framework and EZW Coding	478
18.5.2	Advanced Wavelet Coders: High-Level Characterization	485
18.6	Adaptive Wavelet Transforms: Wavelet Packets	486

18.7	JPEG2000 and Related Developments	490
18.8	Conclusion	491
	References	492
CHAPTER 19	Gradient and Laplacian Edge Detection	495
19.1	Introduction	495
19.2	Gradient-Based Methods	498
	19.2.1 Continuous Gradient	498
	19.2.2 Discrete Gradient Operators	504
19.3	Laplacian-Based Methods	509
	19.3.1 Continuous Laplacian	509
	19.3.2 Discrete Laplacian Operators	510
	19.3.3 The Laplacian of Gaussian (Marr-Hildreth Operator)	512
	19.3.4 Difference of Gaussian	515
19.4	Canny's Method	516
19.5	Approaches for Color and Multispectral Images	518
19.6	Summary	522
	References	522
CHAPTER 20	Diffusion Partial Differential Equations for Edge Detection	525
20.1	Introduction and Motivation	525
	20.1.1 Partial Differential Equations in Image and Video Processing	525
	20.1.2 Edges and Anisotropic Diffusion	525
20.2	Background on Diffusion	526
	20.2.1 Scale Space and Isotropic Diffusion	526
20.3	Anisotropic Diffusion Techniques	528
	20.3.1 The Diffusion Coefficient	528
	20.3.2 The Diffusion PDE	533
	20.3.3 Variational Formulation	535
	20.3.4 Multiresolution Diffusion	537
	20.3.5 Multispectral Anisotropic Diffusion	538
	20.3.6 Speckle Reducing Anisotropic Diffusion	539
20.4	Application of Anisotropic Diffusion to Edge Detection	542
	20.4.1 Edge Detection by Thresholding	542
	20.4.2 Edge Detection from Image Features	543
	20.4.3 Quantitative Evaluation of Edge Detection by Anisotropic Diffusion	543
20.5	Using Vector Diffusion and Parametric Active Contours to Locate Edges	546
	20.5.1 Parametric Active Contours	546
	20.5.2 Gradient Vector Flow	547
	20.5.3 Motion Gradient Vector Flow	548

20.6	Conclusions	549
	References	550
CHAPTER 21	Image Quality Assessment	553
21.1	Introduction	553
21.2	Human Vision Modeling Based Metrics	555
	21.2.1 Building Blocks	556
	21.2.2 HVS-Based Models	561
21.3	Structural Approaches	571
	21.3.1 The Structural Similarity Index	571
	21.3.2 Image Quality Assessment Using SSIM	573
	21.3.3 Relation to HVS-Based Models	576
21.4	Information Theoretic Approaches	578
	21.4.1 Information Theoretic Metrics	578
	21.4.2 Image Quality Assessment Using Information Theoretic Metrics	583
	21.4.3 Relation to HVS-Based Metrics and Structural Similarity	585
21.5	Performance of Image Quality Metrics	587
21.6	Conclusion	588
	References	589
CHAPTER 22	Image Watermarking: Techniques and Applications	597
22.1	Introduction	597
22.2	Applications of Watermarking Techniques	598
22.3	Classification of Watermarking Algorithms	601
22.4	Watermark Embedding, Detection, and Decoding	604
22.5	Copyright Protection Watermarking	606
	22.5.1 Requirements and Metrics	606
	22.5.2 Attacks Against Copyright Protection Watermarking Systems	611
	22.5.3 Benchmarking of Copyright Protection Image Watermarking Algorithms	613
	22.5.4 Spread Spectrum Watermarking	615
	22.5.5 Watermarking with Side Information	627
22.6	Image Content Integrity and Authentication Watermarking ...	636
	References	641
CHAPTER 23	Fingerprint Recognition	649
23.1	Introduction	649
23.2	Emerging Applications	649
23.3	Fingerprint as a Biometric	650
23.4	History of Fingerprints	651