Contents

Preface 9
Acknowledgments 12
The Book Website 13
The DIP4E Support Packages 13
About the Authors 14

1 *Introduction* 17
What is Digital Image Processing? 18
The Origins of Digital Image Processing 19
Examples of Fields that Use Digital Image Processing 23
Fundamental Steps in Digital Image Processing 41
Components of an Image Processing System 44

2 *Digital Image Fundamentals* 47
Elements of Visual Perception 48
Light and the Electromagnetic Spectrum 54
Image Sensing and Acquisition 57
Image Sampling and Quantization 63
Some Basic Relationships Between Pixels 79
Introduction to the Basic Mathematical Tools Used in Digital Image Processing 83

3 *Intensity Transformations and Spatial Filtering* 119
Background 120
Some Basic Intensity Transformation Functions 122
Histogram Processing 133
Fundamentals of Spatial Filtering 153
Smoothing (Lowpass) Spatial Filters 164
Sharpening (Highpass) Spatial Filters 175
Highpass, Bandreject, and Bandpass Filters from Lowpass Filters 188
Combining Spatial Enhancement Methods 191

4 *Filtering in the Frequency Domain* 203

Background 204
Preliminary Concepts 207
Sampling and the Fourier Transform of Sampled Functions 215
The Discrete Fourier Transform of One Variable 225
Extensions to Functions of Two Variables 230
Some Properties of the 2-D DFT and IDFT 240
The Basics of Filtering in the Frequency Domain 260
Image Smoothing Using Lowpass Frequency Domain Filters 272
Image Sharpening Using Highpass Filters 284
Selective Filtering 296
The Fast Fourier Transform 303

5 *Image Restoration and Reconstruction* 317

A Model of the Image Degradation/Restoration process 318
Noise Models 318
Restoration in the Presence of Noise Only—Spatial Filtering 327
Periodic Noise Reduction Using Frequency Domain Filtering 340
Linear, Position-Invariant Degradations 348
Estimating the Degradation Function 352
Inverse Filtering 356
Minimum Mean Square Error (Wiener) Filtering 358
Constrained Least Squares Filtering 363
Geometric Mean Filter 367
Image Reconstruction from Projections 368

6 *Color Image Processing* 399

Color Fundamentals 400
Color Models 405
Pseudocolor Image Processing 420
Basics of Full-Color Image Processing 429
Color Transformations 430

Color Image Smoothing and Sharpening 442
Using Color in Image Segmentation 445
Noise in Color Images 452
Color Image Compression 455

7 *Wavelet and Other Image Transforms* 463

Preliminaries 464
Matrix-based Transforms 466
Correlation 478
Basis Functions in the Time-Frequency Plane 479
Basis Images 483
Fourier-Related Transforms 484
Walsh-Hadamard Transforms 496
Slant Transform 500
Haar Transform 502
Wavelet Transforms 504

8 *Image Compression and Watermarking* 539

Fundamentals 540
Huffman Coding 553
Golomb Coding 556
Arithmetic Coding 561
LZW Coding 564
Run-length Coding 566
Symbol-based Coding 572
Bit-plane Coding 575
Block Transform Coding 576
Predictive Coding 594
Wavelet Coding 614
Digital Image Watermarking 624

9 *Morphological Image Processing* 635

Preliminaries 636
Erosion and Dilation 638
Opening and Closing 644
The Hit-or-Miss Transform 648

Some Basic Morphological Algorithms 652
Morphological Reconstruction 667
Summary of Morphological Operations on Binary Images 673
Grayscale Morphology 674

10 *Image Segmentation* 699

Fundamentals 700
Point, Line, and Edge Detection 701
Thresholding 742
Segmentation by Region Growing and by Region Splitting and Merging 764
Region Segmentation Using Clustering and Superpixels 770
Region Segmentation Using Graph Cuts 777
Segmentation Using Morphological Watersheds 786
The Use of Motion in Segmentation 796

11 *Feature Extraction* 811

Background 812
Boundary Preprocessing 814
Boundary Feature Descriptors 831
Region Feature Descriptors 840
Principal Components as Feature Descriptors 859
Whole-Image Features 868
Scale-Invariant Feature Transform (SIFT) 881

12 *Image Pattern Classification* 903

Background 904
Patterns and Pattern Classes 906
Pattern Classification by Prototype Matching 910
Optimum (Bayes) Statistical Classifiers 923
Neural Networks and Deep Learning 931
Deep Convolutional Neural Networks 964
Some Additional Details of Implementation 987

Bibliography 995
Index 1009