

CONTENTS

LIST OF FIGURES	xxi
LIST OF TABLES	xxxix
FOREWORD	xli
PREFACE	xlili
ACKNOWLEDGMENTS	xlix

PART I IMAGE PROCESSING

1 INTRODUCTION AND OVERVIEW	3
1.1 Motivation / 3	
1.2 Basic Concepts and Terminology / 5	
1.3 Examples of Typical Image Processing Operations / 6	
1.4 Components of a Digital Image Processing System / 10	
1.5 Machine Vision Systems / 12	
1.6 Resources / 14	
1.7 Problems / 18	
2 IMAGE PROCESSING BASICS	21
2.1 Digital Image Representation / 21	
2.1.1 Binary (1-Bit) Images / 23	

2.1.2	Gray-Level (8-Bit) Images / 24	
2.1.3	Color Images / 25	
2.1.4	Compression / 26	
2.2	Image File Formats / 27	
2.3	Basic Terminology / 28	
2.4	Overview of Image Processing Operations / 30	
2.4.1	Global (Point) Operations / 31	
2.4.2	Neighborhood-Oriented Operations / 31	
2.4.3	Operations Combining Multiple Images / 32	
2.4.4	Operations in a Transform Domain / 32	
3	MATLAB BASICS	35
3.1	Introduction to MATLAB / 35	
3.2	Basic Elements of MATLAB / 36	
3.2.1	Working Environment / 36	
3.2.2	Data Types / 37	
3.2.3	Array and Matrix Indexing in MATLAB / 37	
3.2.4	Standard Arrays / 37	
3.2.5	Command-Line Operations / 38	
3.3	Programming Tools: Scripts and Functions / 38	
3.3.1	M-Files / 39	
3.3.2	Operators / 40	
3.3.3	Important Variables and Constants / 42	
3.3.4	Number Representation / 42	
3.3.5	Flow Control / 43	
3.3.6	Code Optimization / 43	
3.3.7	Input and Output / 43	
3.4	Graphics and Visualization / 43	
3.5	Tutorial 3.1: MATLAB—a Guided Tour / 44	
3.6	Tutorial 3.2: MATLAB Data Structures / 46	
3.7	Tutorial 3.3: Programming in MATLAB / 53	
3.8	Problems / 59	
4	THE IMAGE PROCESSING TOOLBOX AT A GLANCE	61
4.1	The Image Processing Toolbox: an Overview / 61	
4.2	Essential Functions and Features / 62	
4.2.1	Displaying Information About an Image File / 62	
4.2.2	Reading an Image File / 64	

- 4.2.3 Data Classes and Data Conversions / 65
- 4.2.4 Displaying the Contents of an Image / 68
- 4.2.5 Exploring the Contents of an Image / 69
- 4.2.6 Writing the Resulting Image onto a File / 70
- 4.3 Tutorial 4.1: MATLAB Image Processing Toolbox—a Guided Tour / 72
- 4.4 Tutorial 4.2: Basic Image Manipulation / 74
- 4.5 Problems / 80

5 IMAGE SENSING AND ACQUISITION

83

- 5.1 Introduction / 83
- 5.2 Light, Color, and Electromagnetic Spectrum / 84
 - 5.2.1 Light and Electromagnetic Spectrum / 84
 - 5.2.2 Types of Images / 85
 - 5.2.3 Light and Color Perception / 86
 - 5.2.4 Color Encoding and Representation / 87
- 5.3 Image Acquisition / 89
 - 5.3.1 Image Sensors / 89
 - 5.3.2 Camera Optics / 92
- 5.4 Image Digitization / 93
 - 5.4.1 Sampling / 95
 - 5.4.2 Quantization / 96
 - 5.4.3 Spatial and Gray-Level Resolution / 97
- 5.5 Problems / 101

6 ARITHMETIC AND LOGIC OPERATIONS

103

- 6.1 Arithmetic Operations: Fundamentals and Applications / 103
 - 6.1.1 Addition / 104
 - 6.1.2 Subtraction / 106
 - 6.1.3 Multiplication and Division / 109
 - 6.1.4 Combining Several Arithmetic Operations / 110
- 6.2 Logic Operations: Fundamentals and Applications / 111
- 6.3 Tutorial 6.1: Arithmetic Operations / 113
- 6.4 Tutorial 6.2: Logic Operations and Region of Interest Processing / 118
- 6.5 Problems / 122

7	GEOMETRIC OPERATIONS	125
7.1	Introduction / 125	
7.2	Mapping and Affine Transformations / 127	
7.3	Interpolation Methods / 130	
7.3.1	The Need for Interpolation / 130	
7.3.2	A Simple Approach to Interpolation / 131	
7.3.3	Zero-Order (Nearest-Neighbor) Interpolation / 132	
7.3.4	First-Order (Bilinear) Interpolation / 132	
7.3.5	Higher Order Interpolations / 132	
7.4	Geometric Operations Using MATLAB / 132	
7.4.1	Zooming, Shrinking, and Resizing / 133	
7.4.2	Translation / 134	
7.4.3	Rotation / 134	
7.4.4	Cropping / 134	
7.4.5	Flipping / 134	
7.5	Other Geometric Operations and Applications / 134	
7.5.1	Warping / 134	
7.5.2	Nonlinear Image Transformations / 135	
7.5.3	Morphing / 137	
7.5.4	Seam Carving / 137	
7.5.5	Image Registration / 137	
7.6	Tutorial 7.1: Image Cropping, Resizing, Flipping, and Rotation / 138	
7.7	Tutorial 7.2: Spatial Transformations and Image Registration / 142	
7.8	Problems / 149	
8	GRAY-LEVEL TRANSFORMATIONS	151
8.1	Introduction / 151	
8.2	Overview of Gray-level (Point) Transformations / 152	
8.3	Examples of Point Transformations / 155	
8.3.1	Contrast Manipulation / 155	
8.3.2	Negative / 157	
8.3.3	Power Law (Gamma) Transformations / 157	
8.3.4	Log Transformations / 159	
8.3.5	Piecewise Linear Transformations / 160	
8.4	Specifying the Transformation Function / 161	
8.5	Tutorial 8.1: Gray-level Transformations / 163	
8.6	Problems / 169	

9	HISTOGRAM PROCESSING	171
9.1	Image Histogram: Definition and Example /	171
9.2	Computing Image Histograms /	173
9.3	Interpreting Image Histograms /	174
9.4	Histogram Equalization /	176
9.5	Direct Histogram Specification /	181
9.6	Other Histogram Modification Techniques /	184
9.6.1	Histogram Sliding /	185
9.6.2	Histogram Stretching /	185
9.6.3	Histogram Shrinking /	186
9.7	Tutorial 9.1: Image Histograms /	188
9.8	Tutorial 9.2: Histogram Equalization and Specification /	191
9.9	Tutorial 9.3: Other Histogram Modification Techniques /	195
9.10	Problems /	200
10	NEIGHBORHOOD PROCESSING	203
10.1	Neighborhood Processing /	203
10.2	Convolution and Correlation /	204
10.2.1	Convolution in the One-Dimensional Domain /	204
10.2.2	Convolution in the Two-Dimensional Domain /	206
10.2.3	Correlation /	208
10.2.4	Dealing with Image Borders /	210
10.3	Image Smoothing (Low-pass Filters) /	211
10.3.1	Mean Filter /	213
10.3.2	Variations /	213
10.3.3	Gaussian Blur Filter /	215
10.3.4	Median and Other Nonlinear Filters /	216
10.4	Image Sharpening (High-pass Filters) /	218
10.4.1	The Laplacian /	219
10.4.2	Composite Laplacian Mask /	220
10.4.3	Directional Difference Filters /	220
10.4.4	Unsharp Masking /	221
10.4.5	High-Boost Filtering /	221
10.5	Region of Interest Processing /	222
10.6	Combining Spatial Enhancement Methods /	223
10.7	Tutorial 10.1: Convolution and Correlation /	223
10.8	Tutorial 10.2: Smoothing Filters in the Spatial Domain /	225

- 10.9 Tutorial 10.3: Sharpening Filters in the Spatial Domain / 228
- 10.10 Problems / 234

11 FREQUENCY-DOMAIN FILTERING

235

- 11.1 Introduction / 235
- 11.2 Fourier Transform: the Mathematical Foundation / 237
 - 11.2.1 Basic Concepts / 237
 - 11.2.2 The 2D Discrete Fourier Transform: Mathematical Formulation / 239
 - 11.2.3 Summary of Properties of the Fourier Transform / 241
 - 11.2.4 Other Mathematical Transforms / 242
- 11.3 Low-pass Filtering / 243
 - 11.3.1 Ideal LPF / 244
 - 11.3.2 Gaussian LPF / 246
 - 11.3.3 Butterworth LPF / 246
- 11.4 High-pass Filtering / 248
 - 11.4.1 Ideal HPF / 248
 - 11.4.2 Gaussian HPF / 250
 - 11.4.3 Butterworth HPF / 250
 - 11.4.4 High-Frequency Emphasis / 251
- 11.5 Tutorial 11.1: 2D Fourier Transform / 252
- 11.6 Tutorial 11.2: Low-pass Filters in the Frequency Domain / 254
- 11.7 Tutorial 11.3: High-pass Filters in the Frequency Domain / 258
- 11.8 Problems / 264

12 IMAGE RESTORATION

265

- 12.1 Modeling of the Image Degradation and Restoration Problem / 265
- 12.2 Noise and Noise Models / 266
 - 12.2.1 Selected Noise Probability Density Functions / 267
 - 12.2.2 Noise Estimation / 269
- 12.3 Noise Reduction Using Spatial-domain Techniques / 269
 - 12.3.1 Mean Filters / 273
 - 12.3.2 Order Statistic Filters / 275
 - 12.3.3 Adaptive Filters / 278
- 12.4 Noise Reduction Using Frequency-domain Techniques / 278
 - 12.4.1 Periodic Noise / 279
 - 12.4.2 Bandreject Filter / 280
 - 12.4.3 Bandpass Filter / 281

- 12.4.4 Notch Filter / 282
- 12.5 Image Deblurring Techniques / 283
 - 12.5.1 Wiener Filtering / 286
- 12.6 Tutorial 12.1: Noise Reduction Using Spatial-domain Techniques / 289
- 12.7 Problems / 296

13 MORPHOLOGICAL IMAGE PROCESSING

299

- 13.1 Introduction / 299
- 13.2 Fundamental Concepts and Operations / 300
 - 13.2.1 The Structuring Element / 301
- 13.3 Dilation and Erosion / 304
 - 13.3.1 Dilation / 305
 - 13.3.2 Erosion / 307
- 13.4 Compound Operations / 310
 - 13.4.1 Opening / 310
 - 13.4.2 Closing / 311
 - 13.4.3 Hit-or-Miss Transform / 313
- 13.5 Morphological Filtering / 314
- 13.6 Basic Morphological Algorithms / 315
 - 13.6.1 Boundary Extraction / 317
 - 13.6.2 Region Filling / 319
 - 13.6.3 Extraction and Labeling of Connected Components / 321
- 13.7 Grayscale Morphology / 322
 - 13.7.1 Dilation and Erosion / 323
 - 13.7.2 Opening and Closing / 323
 - 13.7.3 Top-Hat and Bottom-Hat Transformations / 325
- 13.8 Tutorial 13.1: Binary Morphological Image Processing / 325
- 13.9 Tutorial 13.2: Basic Morphological Algorithms / 330
- 13.10 Problems / 334

14 EDGE DETECTION

335

- 14.1 Formulation of the Problem / 335
- 14.2 Basic Concepts / 336
- 14.3 First-order Derivative Edge Detection / 338
- 14.4 Second-order Derivative Edge Detection / 343
 - 14.4.1 Laplacian of Gaussian / 345
- 14.5 The Canny Edge Detector / 347

- 14.6 Edge Linking and Boundary Detection / 348
 - 14.6.1 The Hough Transform / 349
- 14.7 Tutorial 14.1: Edge Detection / 354
- 14.8 Problems / 363

15 IMAGE SEGMENTATION

365

- 15.1 Introduction / 365
- 15.2 Intensity-based Segmentation / 367
 - 15.2.1 Image Thresholding / 368
 - 15.2.2 Global Thresholding / 369
 - 15.2.3 The Impact of Illumination and Noise on Thresholding / 370
 - 15.2.4 Local Thresholding / 371
- 15.3 Region-based Segmentation / 373
 - 15.3.1 Region Growing / 374
 - 15.3.2 Region Splitting and Merging / 377
- 15.4 Watershed Segmentation / 377
 - 15.4.1 The Distance Transform / 378
- 15.5 Tutorial 15.1: Image Thresholding / 379
- 15.6 Problems / 386

16 COLOR IMAGE PROCESSING

387

- 16.1 The Psychophysics of Color / 387
 - 16.1.1 Basic Concepts / 388
 - 16.1.2 The CIE XYZ Chromaticity Diagram / 390
 - 16.1.3 Perceptually Uniform Color Spaces / 393
 - 16.1.4 ICC Profiles / 395
- 16.2 Color Models / 396
 - 16.2.1 The RGB Color Model / 396
 - 16.2.2 The CMY and CMYK Color Models / 398
 - 16.2.3 The HSV Color Model / 398
 - 16.2.4 The YIQ (NTSC) Color Model / 401
 - 16.2.5 The YCbCr Color Model / 401
- 16.3 Representation of Color Images in MATLAB / 401
 - 16.3.1 RGB Images / 402
 - 16.3.2 Indexed Images / 403
- 16.4 Pseudocolor Image Processing / 406
 - 16.4.1 Intensity Slicing / 406

- 16.4.2 Gray Level to Color Transformations / 407
- 16.4.3 Pseudocoloring in the Frequency Domain / 408
- 16.5 Full-color Image Processing / 409
 - 16.5.1 Color Transformations / 410
 - 16.5.2 Histogram Processing / 412
 - 16.5.3 Color Image Smoothing and Sharpening / 412
 - 16.5.4 Color Noise Reduction / 414
 - 16.5.5 Color-Based Image Segmentation / 414
 - 16.5.6 Color Edge Detection / 417
- 16.6 Tutorial 16.1: Pseudocolor Image Processing / 419
- 16.7 Tutorial 16.2: Full-color Image Processing / 420
- 16.8 Problems / 425

17 IMAGE COMPRESSION AND CODING

427

- 17.1 Introduction / 427
- 17.2 Basic Concepts / 428
 - 17.2.1 Redundancy / 428
 - 17.2.2 Image Encoding and Decoding Model / 431
- 17.3 Lossless and Lossy Compression Techniques / 432
 - 17.3.1 Lossless Compression Techniques / 432
 - 17.3.2 Lossy Compression Techniques / 433
- 17.4 Image Compression Standards / 435
 - 17.4.1 Binary Image Compression Standards / 435
 - 17.4.2 Continuous Tone Still Image Compression Standards / 435
 - 17.4.3 JPEG / 436
 - 17.4.4 JPEG 2000 / 437
 - 17.4.5 JPEG-LS / 437
- 17.5 Image Quality Measures / 438
 - 17.5.1 Subjective Quality Measurement / 438
 - 17.5.2 Objective Quality Measurement / 439
- 17.6 Tutorial 17.1: Image Compression / 440

18 FEATURE EXTRACTION AND REPRESENTATION

447

- 18.1 Introduction / 447
- 18.2 Feature Vectors and Vector Spaces / 448
 - 18.2.1 Invariance and Robustness / 449
- 18.3 Binary Object Features / 450

- 18.3.1 Area / 450
- 18.3.2 Centroid / 450
- 18.3.3 Axis of Least Second Moment / 451
- 18.3.4 Projections / 451
- 18.3.5 Euler Number / 452
- 18.3.6 Perimeter / 453
- 18.3.7 Thinness Ratio / 453
- 18.3.8 Eccentricity / 454
- 18.3.9 Aspect Ratio / 454
- 18.3.10 Moments / 455
- 18.4 Boundary Descriptors / 456
 - 18.4.1 Chain Code, Freeman Code, and Shape Number / 459
 - 18.4.2 Signatures / 461
 - 18.4.3 Fourier Descriptors / 462
- 18.5 Histogram-based (Statistical) Features / 464
- 18.6 Texture Features / 466
- 18.7 Tutorial 18.1: Feature Extraction and Representation / 470
- 18.8 Problems / 474

19 VISUAL PATTERN RECOGNITION

475

- 19.1 Introduction / 475
- 19.2 Fundamentals / 476
 - 19.2.1 Design and Implementation of a Visual Pattern Classifier / 476
 - 19.2.2 Patterns and Pattern Classes / 478
 - 19.2.3 Data Preprocessing / 479
 - 19.2.4 Training and Test Sets / 480
 - 19.2.5 Confusion Matrix / 480
 - 19.2.6 System Errors / 481
 - 19.2.7 Hit Rates, False Alarm Rates, and ROC Curves / 481
 - 19.2.8 Precision and Recall / 482
 - 19.2.9 Distance and Similarity Measures / 485
- 19.3 Statistical Pattern Classification Techniques / 487
 - 19.3.1 Minimum Distance Classifier / 488
 - 19.3.2 k -Nearest Neighbors Classifier / 490
 - 19.3.3 Bayesian Classifier / 490
- 19.4 Tutorial 19.1: Pattern Classification / 491
- 19.5 Problems / 497

PART II VIDEO PROCESSING**20 VIDEO FUNDAMENTALS****501**

- 20.1 Basic Concepts and Terminology / 501
- 20.2 Monochrome Analog Video / 507
 - 20.2.1 Analog Video Raster / 507
 - 20.2.2 Blanking Intervals / 508
 - 20.2.3 Synchronization Signals / 509
 - 20.2.4 Spectral Content of Composite Monochrome Analog Video / 509
- 20.3 Color in Video / 510
- 20.4 Analog Video Standards / 512
 - 20.4.1 NTSC / 513
 - 20.4.2 PAL / 513
 - 20.4.3 SECAM / 514
 - 20.4.4 HDTV / 514
- 20.5 Digital Video Basics / 514
 - 20.5.1 Advantages of Digital Video / 515
 - 20.5.2 Parameters of a Digital Video Sequence / 516
 - 20.5.3 The Audio Component / 517
- 20.6 Analog-to-Digital Conversion / 517
- 20.7 Color Representation and Chroma Subsampling / 520
- 20.8 Digital Video Formats and Standards / 521
 - 20.8.1 The Rec. 601 Digital Video Format / 522
 - 20.8.2 The Common Intermediate Format / 523
 - 20.8.3 The Source Intermediate Format / 524
- 20.9 Video Compression Techniques and Standards / 524
 - 20.9.1 Video Compression Standards, Codecs, and Containers / 525
- 20.10 Video Processing in MATLAB / 526
 - 20.10.1 Reading Video Files / 527
 - 20.10.2 Processing Video Files / 527
 - 20.10.3 Playing Video Files / 527
 - 20.10.4 Writing Video Files / 528
- 20.11 Tutorial 20.1: Basic Digital Video Manipulation in MATLAB / 528
- 20.12 Tutorial 20.2: Working with YUV Video Data / 534
- 20.13 Problems / 539

21 VIDEO SAMPLING RATE AND STANDARDS CONVERSION 541

- 21.1 Video Sampling / 541
- 21.2 Sampling Rate Conversion / 542
- 21.3 Standards Conversion / 543
 - 21.3.1 Deinterlacing / 543
 - 21.3.2 Conversion between PAL and NTSC Signals / 545
 - 21.3.3 Color Space Conversion / 545
 - 21.3.4 Aspect Ratio Conversion / 546
 - 21.3.5 3:2 Pull-Down / 547
- 21.4 Tutorial 21.1: Line Down-Conversion / 548
- 21.5 Tutorial 21.2: Deinterlacing / 550
- 21.6 Tutorial 21.3: NTSC to PAL Conversion / 556
- 21.7 Tutorial 21.4: 3:2 Pull-Down / 557
- 21.8 Problems / 559

22 DIGITAL VIDEO PROCESSING TECHNIQUES AND APPLICATIONS 561

- 22.1 Fundamentals of Motion Estimation and Motion Compensation / 561
- 22.2 General Methodologies in Motion Estimation / 564
 - 22.2.1 Motion Representation / 566
 - 22.2.2 Motion Estimation Criteria / 567
 - 22.2.3 Optimization Methods / 567
- 22.3 Motion Estimation Algorithms / 568
 - 22.3.1 Exhaustive Search Block Matching Algorithm / 568
 - 22.3.2 Fast Algorithms / 570
 - 22.3.3 Hierarchical Block Matching Algorithm / 571
 - 22.3.4 Phase Correlation Method / 573
- 22.4 Video Enhancement and Noise Reduction / 573
 - 22.4.1 Noise Reduction in Video / 574
 - 22.4.2 Interframe Filtering Techniques / 575
- 22.5 Case Study: Object Segmentation and Tracking in the Presence of Complex Background / 576
- 22.6 Tutorial 22.1: Block-based Motion Estimation / 579
- 22.7 Tutorial 22.2: Intraframe and Interframe Filtering Techniques / 585
- 22.8 Problems / 589

Appendix A: HUMAN VISUAL PERCEPTION **591**

- A.1 Introduction / 591
- A.2 The Human Eye / 592
- A.3 Characteristics of Human Vision / 596
 - A.3.1 Resolution, Viewing Distance, and Viewing Angle / 596
 - A.3.2 Detail and Sharpness Perception / 598
 - A.3.3 Optical Transfer Function and Modulation Transfer Function / 599
 - A.3.4 Brightness Perception / 600
 - A.3.5 Contrast Ratio and Contrast Sensitivity Function / 603
 - A.3.6 Perception of Motion / 605
 - A.3.7 Spatiotemporal Resolution and Frequency Response / 606
 - A.3.8 Masking / 608
- A.4 Implications and Applications of Knowledge about the Human Visual System / 609

Appendix B: GUI DEVELOPMENT **611**

- B.1 Introduction / 611
- B.2 GUI File Structure / 611
- B.3 Passing System Control / 613
- B.4 The UserData Object / 615
- B.5 A Working GUI Demo / 616
- B.6 Concluding Remarks / 618

REFERENCES **619**

INDEX **627**

