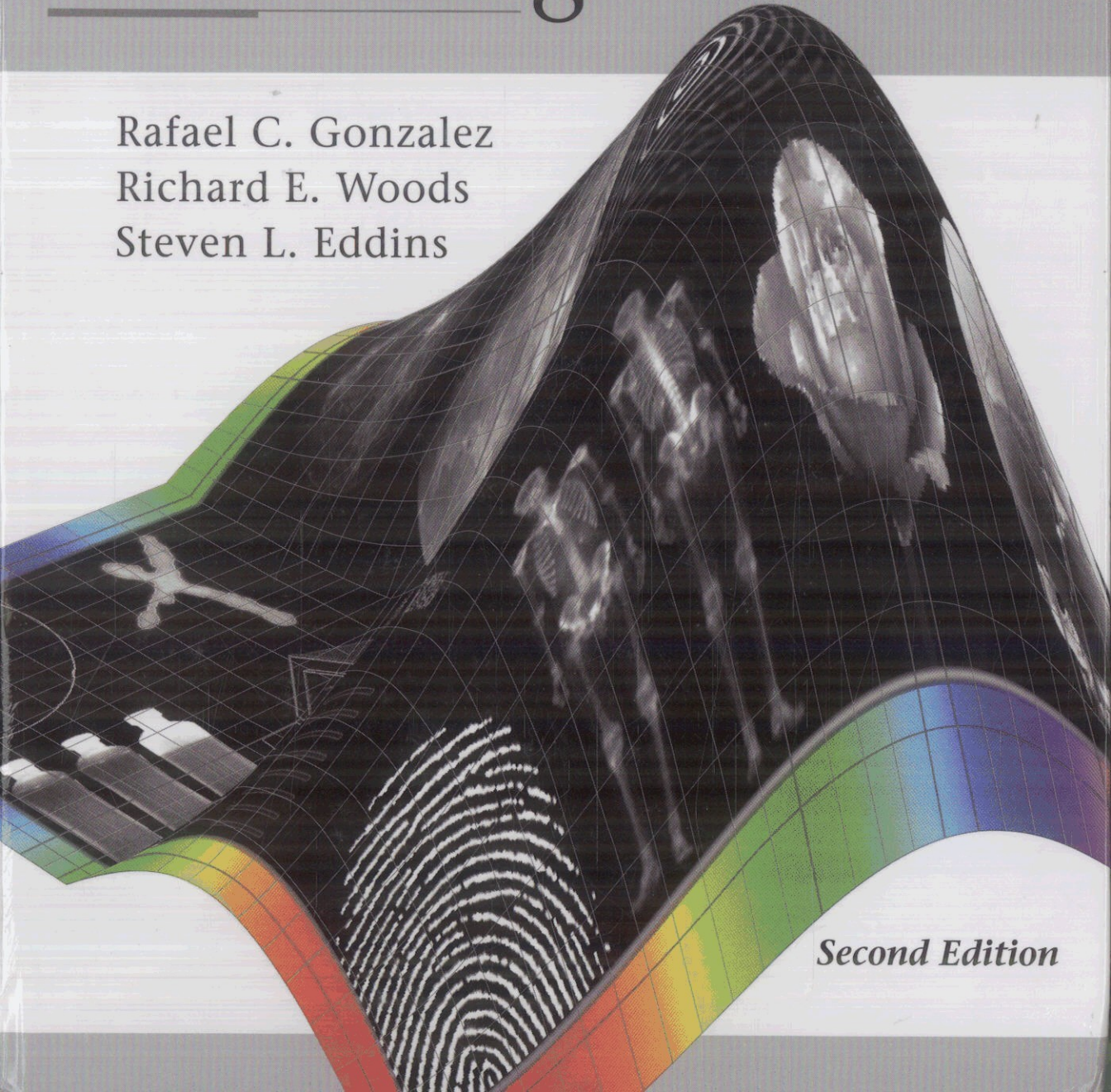


Digital Image USING MATLAB[®] Processing

Rafael C. Gonzalez
Richard E. Woods
Steven L. Eddins



Second Edition

Contents

<i>Preface</i>	<i>xi</i>
<i>Acknowledgements</i>	<i>xiii</i>
<i>About the Authors</i>	<i>xv</i>

1 Introduction 1

Preview 1

1.1	Background	1
1.2	What Is Digital Image Processing?	2
1.3	Background on MATLAB and the Image Processing Toolbox	4
1.4	Areas of Image Processing Covered in the Book	5
1.5	The Book Web Site	7
1.6	Notation	7
1.7	The MATLAB Desktop	7
	1.7.1 Using the MATLAB Editor/Debugger	10
	1.7.2 Getting Help	10
	1.7.3 Saving and Retrieving Work Session Data	11
1.8	How References Are Organized in the Book	11
	<i>Summary</i>	<i>12</i>

2 Fundamentals 13

Preview 13

2.1	Digital Image Representation	13
	2.1.1 Coordinate Conventions	14
	2.1.2 Images as Matrices	15
2.2	Reading Images	15
2.3	Displaying Images	18
2.4	Writing Images	21
2.5	Classes	26
2.6	Image Types	27
	2.6.1 Gray-scale Images	27
	2.6.2 Binary Images	27
	2.6.3 A Note on Terminology	28
2.7	Converting between Classes	28
2.8	Array Indexing	33
	2.8.1 Indexing Vectors	33
	2.8.2 Indexing Matrices	35
	2.8.3 Indexing with a Single Colon	37
	2.8.4 Logical Indexing	38
	2.8.5 Linear Indexing	39
	2.8.6 Selecting Array Dimensions	42

- 2.8.7 Sparse Matrices 42
- 2.9 **Some Important Standard Arrays** 43
- 2.10 **Introduction to M-Function Programming** 44
 - 2.10.1 M-Files 44
 - 2.10.2 Operators 46
 - 2.10.3 Flow Control 57
 - 2.10.4 Function Handles 63
 - 2.10.5 Code Optimization 65
 - 2.10.6 Interactive I/O 71
 - 2.10.7 An Introduction to Cell Arrays and Structures 74
 - Summary* 79

3 *Intensity Transformations and Spatial Filtering* 80

Preview 80

- 3.1 **Background** 80
- 3.2 **Intensity Transformation Functions** 81
 - 3.2.1 Functions `imadjust` and `stretchlim` 82
 - 3.2.2 Logarithmic and Contrast-Stretching Transformations 84
 - 3.2.3 Specifying Arbitrary Intensity Transformations 86
 - 3.2.4 Some Utility M-functions for Intensity Transformations 87
- 3.3 **Histogram Processing and Function Plotting** 93
 - 3.3.1 Generating and Plotting Image Histograms 94
 - 3.3.2 Histogram Equalization 99
 - 3.3.3 Histogram Matching (Specification) 102
 - 3.3.4 Function `adapthisteq` 107
- 3.4 **Spatial Filtering** 109
 - 3.4.1 Linear Spatial Filtering 109
 - 3.4.2 Nonlinear Spatial Filtering 117
- 3.5 **Image Processing Toolbox Standard Spatial Filters** 120
 - 3.5.1 Linear Spatial Filters 120
 - 3.5.2 Nonlinear Spatial Filters 124
- 3.6 **Using Fuzzy Techniques for Intensity Transformations and Spatial Filtering** 128
 - 3.6.1 Background 128
 - 3.6.2 Introduction to Fuzzy Sets 128
 - 3.6.3 Using Fuzzy Sets 133
 - 3.6.4 A Set of Custom Fuzzy M-functions 140
 - 3.6.5 Using Fuzzy Sets for Intensity Transformations 155
 - 3.6.6 Using Fuzzy Sets for Spatial Filtering 158
 - Summary* 163

4 *Filtering in the Frequency Domain* 164

Preview 164

- 4.1 **The 2-D Discrete Fourier Transform** 164
 - 4.2 **Computing and Visualizing the 2-D DFT in MATLAB** 168
 - 4.3 **Filtering in the Frequency Domain** 172
 - 4.3.1 Fundamentals 173
 - 4.3.2 Basic Steps in DFT Filtering 178
 - 4.3.3 An M-function for Filtering in the Frequency Domain 179
 - 4.4 **Obtaining Frequency Domain Filters from Spatial Filters** 180
 - 4.5 **Generating Filters Directly in the Frequency Domain** 185
 - 4.5.1 Creating Meshgrid Arrays for Use in Implementing Filters in the Frequency Domain 186
 - 4.5.2 Lowpass (Smoothing) Frequency Domain Filters 187
 - 4.5.3 Wireframe and Surface Plotting 190
 - 4.6 **Highpass (Sharpening) Frequency Domain Filters** 194
 - 4.6.1 A Function for Highpass Filtering 194
 - 4.6.2 High-Frequency Emphasis Filtering 197
 - 4.7 **Selective Filtering** 199
 - 4.7.1 Bandreject and Bandpass Filters 199
 - 4.7.2 Notchreject and Notchpass Filters 202
- Summary* 208

5 *Image Restoration and Reconstruction* 209

Preview 209

- 5.1 **A Model of the Image Degradation/Restoration Process** 210
- 5.2 **Noise Models** 211
 - 5.2.1 Adding Noise to Images with Function `imnoise` 211
 - 5.2.2 Generating Spatial Random Noise with a Specified Distribution 212
 - 5.2.3 Periodic Noise 220
 - 5.2.4 Estimating Noise Parameters 224
- 5.3 **Restoration in the Presence of Noise Only—Spatial Filtering** 229
 - 5.3.1 Spatial Noise Filters 229
 - 5.3.2 Adaptive Spatial Filters 233
- 5.4 **Periodic Noise Reduction Using Frequency Domain Filtering** 236
- 5.5 **Modeling the Degradation Function** 237
- 5.6 **Direct Inverse Filtering** 240
- 5.7 **Wiener Filtering** 240
- 5.8 **Constrained Least Squares (Regularized) Filtering** 244
- 5.9 **Iterative Nonlinear Restoration Using the Lucy-Richardson Algorithm** 246
- 5.10 **Blind Deconvolution** 250
- 5.11 **Image Reconstruction from Projections** 251
 - 5.11.1 Background 252
 - 5.11.2 Parallel-Beam Projections and the Radon Transform 254
 - 5.11.3 The Fourier Slice Theorem and Filtered Backprojections 257
 - 5.11.4 Filter Implementation 258

- 5.11.5 Reconstruction Using Fan-Beam Filtered Backprojections 259
- 5.11.6 Function `radon` 260
- 5.11.7 Function `iradon` 263
- 5.11.8 Working with Fan-Beam Data 268
- Summary* 277

6 *Geometric Transformations and Image Registration* 278

Preview 278

- 6.1 **Transforming Points** 278
- 6.2 **Affine Transformations** 283
- 6.3 **Projective Transformations** 287
- 6.4 **Applying Geometric Transformations to Images** 288
- 6.5 **Image Coordinate Systems in MATLAB** 291
 - 6.5.1 Output Image Location 293
 - 6.5.2 Controlling the Output Grid 297
- 6.6 **Image Interpolation** 299
 - 6.6.1 Interpolation in Two Dimensions 302
 - 6.6.2 Comparing Interpolation Methods 302
- 6.7 **Image Registration** 305
 - 6.7.1 Registration Process 306
 - 6.7.2 Manual Feature Selection and Matching Using `cpselect` 306
 - 6.7.3 Inferring Transformation Parameters Using `cp2tform` 307
 - 6.7.4 Visualizing Aligned Images 307
 - 6.7.5 Area-Based Registration 311
 - 6.7.5 Automatic Feature-Based Registration 316
- Summary* 317

7 *Color Image Processing* 318

Preview 318

- 7.1 **Color Image Representation in MATLAB** 318
 - 7.1.1 RGB Images 318
 - 7.1.2 Indexed Images 321
 - 7.1.3 Functions for Manipulating RGB and Indexed Images 323
- 7.2 **Converting Between Color Spaces** 328
 - 7.2.1 NTSC Color Space 328
 - 7.2.2 The YCbCr Color Space 329
 - 7.2.3 The HSV Color Space 329
 - 7.2.4 The CMY and CMYK Color Spaces 330
 - 7.2.5 The HSI Color Space 331
 - 7.2.6 Device-Independent Color Spaces 340
- 7.3 **The Basics of Color Image Processing** 349
- 7.4 **Color Transformations** 350
- 7.5 **Spatial Filtering of Color Images** 360

- 7.5.1 Color Image Smoothing 360
- 7.5.2 Color Image Sharpening 365
- 7.6 **Working Directly in RGB Vector Space 366**
 - 7.6.1 Color Edge Detection Using the Gradient 366
 - 7.6.2 Image Segmentation in RGB Vector Space 372
 - Summary 376*

8 *Wavelets 377*

- Preview 377*
- 8.1 **Background 377**
- 8.2 **The Fast Wavelet Transform 380**
 - 8.2.1 FWTs Using the Wavelet Toolbox 381
 - 8.2.2 FWTs without the Wavelet Toolbox 387
- 8.3 **Working with Wavelet Decomposition Structures 396**
 - 8.3.1 Editing Wavelet Decomposition Coefficients without the Wavelet Toolbox 399
 - 8.3.2 Displaying Wavelet Decomposition Coefficients 404
- 8.4 **The Inverse Fast Wavelet Transform 408**
- 8.5 **Wavelets in Image Processing 414**
 - Summary 419*

9 *Image Compression 420*

- Preview 420*
- 9.1 **Background 421**
- 9.2 **Coding Redundancy 424**
 - 9.2.1 Huffman Codes 427
 - 9.2.2 Huffman Encoding 433
 - 9.2.3 Huffman Decoding 439
- 9.3 **Spatial Redundancy 446**
- 9.4 **Irrelevant Information 453**
- 9.5 **JPEG Compression 456**
 - 9.5.1 JPEG 456
 - 9.5.2 JPEG 2000 464
- 9.6 **Video Compression 472**
 - 9.6.1 MATLAB Image Sequences and Movies 473
 - 9.6.2 Temporal Redundancy and Motion Compensation 476
 - Summary 485*

10 *Morphological Image Processing 486*

- Preview 486*
- 10.1 **Preliminaries 487**
 - 10.1.1 Some Basic Concepts from Set Theory 487
 - 10.1.2 Binary Images, Sets, and Logical Operators 489
- 10.2 **Dilation and Erosion 490**

- 10.2.1 Dilation 490
- 10.2.2 Structuring Element Decomposition 493
- 10.2.3 The `strel` Function 494
- 10.2.4 Erosion 497
- 10.3 Combining Dilation and Erosion 500**
 - 10.3.1 Opening and Closing 500
 - 10.3.2 The Hit-or-Miss Transformation 503
 - 10.3.3 Using Lookup Tables 506
 - 10.3.4 Function `bwmorph` 511
- 10.4 Labeling Connected Components 514**
- 10.5 Morphological Reconstruction 518**
 - 10.5.1 Opening by Reconstruction 518
 - 10.5.2 Filling Holes 520
 - 10.5.3 Clearing Border Objects 521
- 10.6 Gray-Scale Morphology 521**
 - 10.6.1 Dilation and Erosion 521
 - 10.6.2 Opening and Closing 524
 - 10.6.3 Reconstruction 530
 - Summary* 534

11 *Image Segmentation* 535

Preview 535

- 11.1 Point, Line, and Edge Detection 536**
 - 11.1.1 Point Detection 536
 - 11.1.2 Line Detection 538
 - 11.1.3 Edge Detection Using Function `edge` 541
- 11.2 Line Detection Using the Hough Transform 549**
 - 11.2.1 Background 551
 - 11.2.2 Toolbox Hough Functions 552
- 11.3 Thresholding 557**
 - 11.3.1 Foundation 557
 - 11.3.2 Basic Global Thresholding 559
 - 11.3.3 Optimum Global Thresholding Using Otsu's Method 561
 - 11.3.4 Using Image Smoothing to Improve Global Thresholding 565
 - 11.3.5 Using Edges to Improve Global Thresholding 567
 - 11.3.6 Variable Thresholding Based on Local Statistics 571
 - 11.3.7 Image Thresholding Using Moving Averages 575
- 11.4 Region-Based Segmentation 578**
 - 11.4.1 Basic Formulation 578
 - 11.4.2 Region Growing 578
 - 11.4.3 Region Splitting and Merging 582
- 11.5 Segmentation Using the Watershed Transform 588**
 - 11.5.1 Watershed Segmentation Using the Distance Transform 589
 - 11.5.2 Watershed Segmentation Using Gradients 591
 - 11.5.3 Marker-Controlled Watershed Segmentation 593

12 Representation and Description 597

Preview 597

12.1 Background 597

12.1.1 Functions for Extracting Regions and Their Boundaries 598

12.1.2 Some Additional MATLAB and Toolbox Functions Used
in This Chapter 603

12.1.3 Some Basic Utility M-Functions 604

12.2 Representation 606

12.2.1 Chain Codes 606

12.2.2 Polygonal Approximations Using Minimum-Perimeter
Polygons 610

12.2.3 Signatures 619

12.2.4 Boundary Segments 622

12.2.5 Skeletons 623

12.3 Boundary Descriptors 625

12.3.1 Some Simple Descriptors 625

12.3.2 Shape Numbers 626

12.3.3 Fourier Descriptors 627

12.3.4 Statistical Moments 632

12.3.5 Corners 633

12.4 Regional Descriptors 641

12.4.1 Function `regionprops` 642

12.4.2 Texture 644

12.4.3 Moment Invariants 656

12.5 Using Principal Components for Description 661

Summary 672

13 Object Recognition 674

Preview 674

13.1 Background 674

13.2 Computing Distance Measures in MATLAB 675

13.3 Recognition Based on Decision-Theoretic Methods 679

13.3.1 Forming Pattern Vectors 680

13.3.2 Pattern Matching Using Minimum-Distance Classifiers 680

13.3.3 Matching by Correlation 681

13.3.4 Optimum Statistical Classifiers 684

13.3.5 Adaptive Learning Systems 691

13.4 Structural Recognition 691

13.4.1 Working with Strings in MATLAB 692

13.4.2 String Matching 701

Summary 706

Appendix A	<i>M-Function Summary</i>	707
Appendix B	<i>ICE and MATLAB Graphical User Interfaces</i>	724
Appendix C	<i>Additional Custom M-functions</i>	750
	<i>Bibliography</i>	813
	<i>Index</i>	817