

Wilhelm Burger · Mark J. Burge

Principles of Digital Image Processing

Core Algorithms

With 134 figures and 10 tables

Springer-Verlag

Berlin Heidelberg New York

London Paris Tokyo

Hong Kong Barcelona

Budapest

Contents

Preface	v
1. Introduction	1
1.1 Programming with Images	2
1.2 Image Analysis	3
2. Regions in Binary Images	5
2.1 Finding Image Regions	6
2.1.1 Region Labeling with Flood Filling	6
2.1.2 Sequential Region Labeling	11
2.1.3 Region Labeling—Summary	17
2.2 Region Contours	17
2.2.1 External and Internal Contours	18
2.2.2 Combining Region Labeling and Contour Finding	20
2.2.3 Implementation	22
2.2.4 Example	25
2.3 Representing Image Regions	26
2.3.1 Matrix Representation	26
2.3.2 Run Length Encoding	27
2.3.3 Chain Codes	28
2.4 Properties of Binary Regions	32
2.4.1 Shape Features	32
2.4.2 Geometric Features	33
2.4.3 Statistical Shape Properties	36
2.4.4 Moment-Based Geometrical Properties	38
2.4.5 Projections	44

2.4.6	Topological Properties	45
2.5	Exercises	46
3.	Detecting Simple Curves	49
3.1	Salient Structures	49
3.2	Hough Transform	50
3.2.1	Parameter Space	51
3.2.2	Accumulator Array	54
3.2.3	A Better Line Representation	54
3.3	Implementing the Hough Transform	55
3.3.1	Filling the Accumulator Array	56
3.3.2	Analyzing the Accumulator Array	56
3.3.3	Hough Transform Extensions	60
3.4	Hough Transform for Circles and Ellipses	63
3.4.1	Circles and Arcs	64
3.4.2	Ellipses	66
3.5	Exercises	67
4.	Corner Detection	69
4.1	Points of Interest	69
4.2	Harris Corner Detector	70
4.2.1	Local Structure Matrix	70
4.2.2	Corner Response Function (CRF)	71
4.2.3	Determining Corner Points	72
4.2.4	Example	72
4.3	Implementation	72
4.3.1	Step 1: Computing the Corner Response Function	76
4.3.2	Step 2: Selecting “Good” Corner Points	79
4.3.3	Displaying the Corner Points	83
4.3.4	Summary	83
4.4	Exercises	84
5.	Color Quantization	85
5.1	Scalar Color Quantization	86
5.2	Vector Quantization	88
5.2.1	Popularity algorithm	88
5.2.2	Median-cut algorithm	88
5.2.3	Octree algorithm	89
5.2.4	Other methods for vector quantization	94
5.3	Exercises	95

6. Colorimetric Color Spaces	97
6.1 CIE Color Spaces	98
6.1.1 CIE XYZ color space	98
6.1.2 CIE x, y chromaticity	99
6.1.3 Standard illuminants	101
6.1.4 Gamut	102
6.1.5 Variants of the CIE color space	103
6.2 CIE $L^*a^*b^*$	104
6.2.1 Transformation CIE XYZ $\rightarrow L^*a^*b^*$	104
6.2.2 Transformation $L^*a^*b^* \rightarrow$ CIE XYZ	105
6.2.3 Measuring color differences	105
6.3 sRGB	106
6.3.1 Linear vs. nonlinear color components	107
6.3.2 Transformation CIE XYZ \rightarrow sRGB	108
6.3.3 Transformation sRGB \rightarrow CIE XYZ	108
6.3.4 Calculating with sRGB values	109
6.4 Adobe RGB	111
6.5 Chromatic Adaptation	111
6.5.1 XYZ scaling	112
6.5.2 Bradford adaptation	113
6.6 Colorimetric Support in Java	114
6.6.1 sRGB colors in Java	114
6.6.2 Profile connection space (PCS)	115
6.6.3 Color-related Java classes	118
6.6.4 A $L^*a^*b^*$ color space implementation	120
6.6.5 ICC profiles	121
6.7 Exercises	124
7. Introduction to Spectral Techniques	125
7.1 The Fourier Transform	126
7.1.1 Sine and Cosine Functions	126
7.1.2 Fourier Series of Periodic Functions	130
7.1.3 Fourier Integral	130
7.1.4 Fourier Spectrum and Transformation	131
7.1.5 Fourier Transform Pairs	132
7.1.6 Important Properties of the Fourier Transform	136
7.2 Working with Discrete Signals	137
7.2.1 Sampling	137
7.2.2 Discrete and Periodic Functions	144
7.3 The Discrete Fourier Transform (DFT)	144
7.3.1 Definition of the DFT	144

7.3.2	Discrete Basis Functions	147
7.3.3	Aliasing Again!	148
7.3.4	Units in Signal and Frequency Space	152
7.3.5	Power Spectrum	153
7.4	Implementing the DFT	154
7.4.1	Direct Implementation	154
7.4.2	Fast Fourier Transform (FFT)	155
7.5	Exercises	156
8.	The Discrete Fourier Transform in 2D	157
8.1	Definition of the 2D DFT	157
8.1.1	2D Basis Functions	158
8.1.2	Implementing the Two-Dimensional DFT	158
8.2	Visualizing the 2D Fourier Transform	162
8.2.1	Range of Spectral Values	162
8.2.2	Centered Representation	162
8.3	Frequencies and Orientation in 2D	164
8.3.1	Effective Frequency	164
8.3.2	Frequency Limits and Aliasing in 2D	164
8.3.3	Orientation	165
8.3.4	Normalizing the 2D Spectrum	166
8.3.5	Effects of Periodicity	167
8.3.6	Windowing	169
8.3.7	Windowing Functions	169
8.4	2D Fourier Transform Examples	171
8.5	Applications of the DFT	175
8.5.1	Linear Filter Operations in Frequency Space	175
8.5.2	Linear Convolution versus Correlation	177
8.5.3	Inverse Filters	178
8.6	Exercises	180
9.	The Discrete Cosine Transform (DCT)	183
9.1	One-Dimensional DCT	183
9.1.1	DCT Basis Functions	184
9.1.2	Implementing the One-Dimensional DCT	186
9.2	Two-Dimensional DCT	187
9.2.1	Separability	187
9.2.2	Examples	188
9.3	Other Spectral Transforms	188
9.4	Exercises	190

10. Geometric Operations	191
10.1 2D Mapping Function	193
10.1.1 Simple Mappings	193
10.1.2 Homogeneous Coordinates	194
10.1.3 Affine (Three-Point) Mapping	195
10.1.4 Projective (Four-Point) Mapping	197
10.1.5 Bilinear Mapping	203
10.1.6 Other Nonlinear Image Transformations	204
10.1.7 Local Image Transformations	207
10.2 Resampling the Image	209
10.2.1 Source-to-Target Mapping	209
10.2.2 Target-to-Source Mapping	210
10.3 Interpolation	210
10.3.1 Simple Interpolation Methods	211
10.3.2 Ideal Interpolation	213
10.3.3 Interpolation by Convolution	217
10.3.4 Cubic Interpolation	217
10.3.5 Spline Interpolation	219
10.3.6 Lanczos Interpolation	223
10.3.7 Interpolation in 2D	225
10.3.8 Aliasing	234
10.4 Java Implementation	238
10.4.1 Geometric Transformations	238
10.4.2 Pixel Interpolation	248
10.4.3 Sample Applications	251
10.5 Exercises	253
11. Comparing Images	255
11.1 Template Matching in Intensity Images	257
11.1.1 Distance between Image Patterns	258
11.1.2 Implementation	266
11.1.3 Matching under Rotation and Scaling	267
11.2 Matching Binary Images	269
11.2.1 Direct Comparison	269
11.2.2 The Distance Transform	270
11.2.3 Chamfer Matching	274
11.3 Exercises	278
A. Mathematical Notation	279
A.1 Symbols	279
A.2 Set Operators	281
A.3 Complex Numbers	282

B. Source Code	283
B.1 Combined Region Labeling and Contour Tracing	283
B.1.1 Contour_Tracing_Plugin (Class)	283
B.1.2 Contour (Class)	285
B.1.3 BinaryRegion (Class)	286
B.1.4 ContourTracer (Class)	287
B.1.5 ContourOverlay (Class)	292
B.2 Harris Corner Detector	294
B.2.1 Harris_Corner_Plugin (Class)	294
B.2.2 File Corner (Class)	295
B.2.3 File HarrisCornerDetector (Class)	296
B.3 Median-Cut Color Quantization	301
B.3.1 ColorQuantizer (Interface)	301
B.3.2 MedianCutQuantizer (Class)	301
B.3.3 ColorHistogram (Class)	309
B.3.4 Median_Cut_Quantization (Class)	310
Bibliography	313
Index	321