

# Contents

<i>Preface</i>	xi
<b>1 Introduction</b>	<b>1</b>
1.1 Overview	1
1.2 Human and computer vision	1
1.3 The human vision system	3
1.3.1 The eye	4
1.3.2 The neural system	6
1.3.3 Processing	7
1.4 Computer vision systems	9
1.4.1 Cameras	10
1.4.2 Computer interfaces	12
1.4.3 Processing an image	14
1.5 Mathematical systems	15
1.5.1 Mathematical tools	16
1.5.2 Hello Mathcad, hello images!	16
1.5.3 Hello Matlab!	21
1.6 Associated literature	24
1.6.1 Journals and magazines	24
1.6.2 Textbooks	25
1.6.3 The web	28
1.7 Conclusions	29
1.8 References	29
<b>2 Images, sampling and frequency domain processing</b>	<b>33</b>
2.1 Overview	33
2.2 Image formation	34
2.3 The Fourier transform	37
2.4 The sampling criterion	43
2.5 The discrete Fourier transform	47
2.5.1 One-dimensional transform	47
2.5.2 Two-dimensional transform	49
2.6 Other properties of the Fourier transform	54
2.6.1 Shift invariance	54
2.6.2 Rotation	56
2.6.3 Frequency scaling	56
2.6.4 Superposition (linearity)	57

2.7	Transforms other than Fourier	58
2.7.1	Discrete cosine transform	58
2.7.2	Discrete Hartley transform	59
2.7.3	Introductory wavelets: the Gabor wavelet	61
2.7.4	Other transforms	63
2.8	Applications using frequency domain properties	64
2.9	Further reading	65
2.10	References	66
<b>3</b>	<b>Basic image processing operations</b>	<b>69</b>
3.1	Overview	69
3.2	Histograms	70
3.3	Point operators	71
3.3.1	Basic point operations	71
3.3.2	Histogram normalization	74
3.3.3	Histogram equalization	75
3.3.4	Thresholding	77
3.4	Group operations	81
3.4.1	Template convolution	81
3.4.2	Averaging operator	84
3.4.3	On different template size	87
3.4.4	Gaussian averaging operator	88
3.5	Other statistical operators	90
3.5.1	More on averaging	90
3.5.2	Median filter	91
3.5.3	Mode filter	94
3.5.4	Anisotropic diffusion	96
3.5.5	Force field transform	101
3.5.6	Comparison of statistical operators	102
3.6	Mathematical morphology	103
3.6.1	Morphological operators	104
3.6.2	Grey-level morphology	107
3.6.3	Grey-level erosion and dilation	108
3.6.4	Minkowski operators	109
3.7	Further reading	112
3.8	References	113
<b>4</b>	<b>Low-level feature extraction (including edge detection)</b>	<b>115</b>
4.1	Overview	115
4.2	First order edge detection operators	117
4.2.1	Basic operators	117
4.2.2	Analysis of the basic operators	119
4.2.3	Prewitt edge detection operator	121
4.2.4	Sobel edge detection operator	123
4.2.5	Canny edge detection operator	129

4.3	Second order edge detection operators	137
4.3.1	Motivation	137
4.3.2	Basic operators: the Laplacian	137
4.3.3	Marr–Hildreth operator	139
4.4	Other edge detection operators	144
4.5	Comparison of edge detection operators	145
4.6	Further reading on edge detection	146
4.7	Phase congruency	147
4.8	Localized feature extraction	152
4.8.1	Detecting image curvature (corner extraction)	153
4.8.1.1	Definition of curvature	153
4.8.1.2	Computing differences in edge direction	154
4.8.1.3	Measuring curvature by changes in intensity (differentiation)	156
4.8.1.4	Moravec and Harris detectors	159
4.8.1.5	Further reading on curvature	163
4.8.2	Modern approaches: region/patch analysis	164
4.8.2.1	Scale invariant feature transform	164
4.8.2.2	Saliency	166
4.8.2.3	Other techniques and performance issues	167
4.9	Describing image motion	167
4.9.1	Area-based approach	168
4.9.2	Differential approach	171
4.9.3	Further reading on optical flow	177
4.10	Conclusions	178
4.11	References	178
<b>5</b>	<b>Feature extraction by shape matching</b>	<b>183</b>
5.1	Overview	183
5.2	Thresholding and subtraction	184
5.3	Template matching	186
5.3.1	Definition	186
5.3.2	Fourier transform implementation	193
5.3.3	Discussion of template matching	196
5.4	Hough transform	196
5.4.1	Overview	196
5.4.2	Lines	197
5.4.3	Hough transform for circles	203
5.4.4	Hough transform for ellipses	207
5.4.5	Parameter space decomposition	210
5.4.5.1	Parameter space reduction for lines	210
5.4.5.2	Parameter space reduction for circles	212
5.4.5.3	Parameter space reduction for ellipses	217
5.5	Generalized Hough transform	221
5.5.1	Formal definition of the GHT	221
5.5.2	Polar definition	223

5.5.3	The GHT technique	224
5.5.4	Invariant GHT	228
5.6	Other extensions to the Hough transform	235
5.7	Further reading	236
5.8	References	237
<b>6</b>	<b>Flexible shape extraction (snakes and other techniques)</b>	<b>241</b>
6.1	Overview	241
6.2	Deformable templates	242
6.3	Active contours (snakes)	244
6.3.1	Basics	244
6.3.2	The greedy algorithm for snakes	246
6.3.3	Complete (Kass) snake implementation	252
6.3.4	Other snake approaches	257
6.3.5	Further snake developments	257
6.3.6	Recent developments in contour models	261
6.4	Shape skeletonization	266
6.4.1	Distance transforms	266
6.4.2	Symmetry	268
6.5	Flexible shape models: active shape and active appearance	272
6.6	Further reading	275
6.7	References	276
<b>7</b>	<b>Object description</b>	<b>281</b>
7.1	Overview	281
7.2	Boundary descriptions	282
7.2.1	Boundary and region	282
7.2.2	Chain codes	283
7.2.3	Fourier descriptors	285
7.2.3.1	Basis of Fourier descriptors	286
7.2.3.2	Fourier expansion	287
7.2.3.3	Shift invariance	289
7.2.3.4	Discrete computation	290
7.2.3.5	Cumulative angular function	292
7.2.3.6	Elliptic Fourier descriptors	301
7.2.3.7	Invariance	305
7.3	Region descriptors	311
7.3.1	Basic region descriptors	311
7.3.2	Moments	315
7.3.2.1	Basic properties	315
7.3.2.2	Invariant moments	318
7.3.2.3	Zernike moments	320
7.3.2.4	Other moments	324
7.4	Further reading	325
7.5	References	326

<b>8</b>	<b>Introduction to texture description, segmentation and classification</b>	<b>329</b>
8.1	Overview	329
8.2	What is texture?	330
8.3	Texture description	332
8.3.1	Performance requirements	332
8.3.2	Structural approaches	332
8.3.3	Statistical approaches	335
8.3.4	Combination approaches	337
8.4	Classification	339
8.4.1	The $k$ -nearest neighbour rule	339
8.4.2	Other classification approaches	343
8.5	Segmentation	343
8.6	Further reading	345
8.7	References	346
<b>9</b>	<b>Appendix 1: Example worksheets</b>	<b>349</b>
9.1	Example Mathcad worksheet for Chapter 3	349
9.2	Example Matlab worksheet for Chapter 4	352
<b>10</b>	<b>Appendix 2: Camera geometry fundamentals</b>	<b>355</b>
10.1	Image geometry	355
10.2	Perspective camera	355
10.3	Perspective camera model	357
10.3.1	Homogeneous coordinates and projective geometry	357
10.3.1.1	Representation of a line and duality	358
10.3.1.2	Ideal points	358
10.3.1.3	Transformations in the projective space	359
10.3.2	Perspective camera model analysis	360
10.3.3	Parameters of the perspective camera model	363
10.4	Affine camera	364
10.4.1	Affine camera model	365
10.4.2	Affine camera model and the perspective projection	366
10.4.3	Parameters of the affine camera model	368
10.5	Weak perspective model	369
10.6	Example of camera models	371
10.7	Discussion	379
10.8	References	380
<b>11</b>	<b>Appendix 3: Least squares analysis</b>	<b>381</b>
11.1	The least squares criterion	381
11.2	Curve fitting by least squares	382

<b>12 Appendix 4: Principal components analysis</b>	<b>385</b>
12.1 Introduction	385
12.2 Data	385
12.3 Covariance	386
12.4 Covariance matrix	388
12.5 Data transformation	389
12.6 Inverse transformation	390
12.7 Eigenproblem	391
12.8 Solving the eigenproblem	392
12.9 PCA method summary	392
12.10 Example	393
12.11 References	398
<i>Index</i>	399